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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, May 19, 1903.

The 177th meeting was held this date at 12 West 31st Street.

President Charles F. Scott called the meeting to order at 8:25 P.M. and said:

This is our annual meeting for the transaction of Institute business. Proxies have been received and a Proxy Committee will now be appointed whose functions will be to look over and check up the list of proxies. The Secretary has tabulated these so that the duties of the Committee will be light. I will appoint as such Committee Messrs. Lardner, Nicholson and Walker. The Secretary will give a report of the elections held in the Board of Directors this afternoon for transfers from associate to full membership.

SECRETARY POPE:—At a meeting of the Board of Directors this afternoon, the following 140 Associates were elected:

NAME.	ADDRESS.	ENDORSERS.
ABELL, HARRY CLINTON,	Engineer, Montgomery Light and Water Power Co., Montgomery, Ala.	Ralph D. Mershon. H. L. Doherty. J. B. Cahoon.
ABENDROTH, WILLIAM PHILIP,	Student, Columbia University; residence, 549 West 152d St., New York City.	G. F. Sever. F. B. Crocker. Fitzhugh Townsend.
ACKERMAN, ALEXANDER HENRY,	Electrical Engineer, New York Edison Co., 55 Duane St., residence, 86 Pierrepont St., Brooklyn, N. Y.	H. A. Lardner. C. D. Haskins. C. W. Rice.
ANDRUS, LUCIUS BUCKLEY,	Engineer, Westinghouse Electric & Mfg. Co., residence, 42 W. State St., Columbus, Ohio.	C. F. Scott. W. K. Dunlap. C. E. Downton.
ANGUS, WILLIAM GRAHAM,	Electrical Engineer, The Hamilton Electric Light and Cataract Power Co., Hamilton, Ont.	A. L. Mudge. H. R. Leyden. J. Sangster.
AYRES, MILAN VALENTINE,	Electrical Engineer, Boston and Worcester Street Railway Co., South Framingham, Mass.	A. E. Averett. H. G. Reist. J. E. Woodbridge

BARKER, RALPH EMERSON, Assistant Electrical Engineer, General Electric Co.; residence, 24 Chase St., Lynn, Mass.	W. C. Fish. Elihu Thomson. E. J. Houston.
BEATTYS, WILLIAM HENRY, JR., Chicago Representative, The Cutler Hammer Mfg. Co., 1232 Monadnock Block, Chicago; residence, Western Springs, Cook Co., Ill.	T. P. Gaylord. G. A. Damon. James Lyman.
BEDELL, CHARLES HAMPTON, Head of Laboratory, The Electro-Dynamic Co., 224 Ionic St., Philadelphia; residence, Swarthmore, Pa.	Carl Hering. C. W. Woodward. Hugh Lesley.
BERG, MAX A., Secretary Porter & Berg, 309 Dearborn St., Chicago, Ill.	G. A. Damon. C. R. Sturtevant. R. H. Pierce.
BESSEY, CARL ATHEARN, Draughtsman, General Electric Co., residence, 1219 State St., Schenectady, N.Y.	R. N. Williams. C. P. Steinmetz. E. B. Raymond.
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BRAY, CHARLES AYERS, Electrical Engineer, General Electric Co., Schenectady, N. Y.	F. O. Blackwell. H. G. Reist. E. B. Raymond.
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BROWN, SYDNEY WILLIAM, Switchboard-man, Waterside Station, New York Edison Co.; residence, 414 Central Park West, New York City.	H. W. Leitch. W. H. Lawrence. W. F. Wells.
BRYANT, WALDO CALVIN, Manager, The Bryant Electrical Co., Bridgeport, Conn.	C. A. Terry. Hubert Howson. C. F. Scott.
BURNS, WILLIAM GIBSON, Electrical Engineer, with Jabez Burns & Sons, 542 Greenwich St.; residence, 423 W. 117th St., New York City.	Morton Arendt. F. B. Crocker. G. F. Sever.
BUTTERWORTH, ISAAC NELSON, General Manager, Tri-City Electric Co.; residence, 405 Brady, Davenport, Iowa.	M. C. Beebe. M. W. Hawks. Edward Bennett.
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NAYLOR, CHARLES WILLIAM,	Mechanical Engineer, Marshall Field and Co., 83 State St.; residence, 1592 Lexington St., Chicago, Ill.	F. J. Pearsons. C. M. Wilkes. L. A. Ferguson.
OLMSTED, HARRY WILLIAM,	Electrical Inspector, with Fremont Wilson, Hackensack, N. J.	Fremont Wilson. Townsend Wolcott. A. F. Westervelt.
PARKER, CAPT. CHARLES FOSTER,	In charge Instruction of Electrician Sergeants, School of Submarine Defense, Fort Totten, Willets Point, N. Y.	Lambert Schmidt. Samuel Reber. Edgar Russell.
PAULY, KARL ALMON,	Engineer, General Electric Co.; residence, 1 Division St., Schenectady, N. Y.	A. E. Averrett. W. I. Slichter. H. G. Reist.
PEASE, HENRY MARK,	Telephone Engineer, The Western Electric Co., No. Woolwich, E. London, Eng.	Robert Tervet. C. E. Scribner. F. L. Gilman.
PIERCE, GEORGE ALBERT, JR.,	Assistant Superintendent of Electrical Department, William Cramp & Sons, Ship and Engine Building Co.; residence, 861 E. Thompson St., Philadelphia, Pa.	A. J. Rowland. George McQuilkinJr Carl Hering.
PIETSCH, JAMES ANDERSON,	Chief Engineer, The San Juan Light and Transit Co., San Juan, Porto Rico.	Samuel Sheldon. S. W. Aslie. Hobart Mason.
PRATT, CHARLES RICHARDSON,	Mechanical Engineer, Marine Engine and Machine Co., Harrison; residence, Montclair, N. J.	S. F. Weston B. N. Jones. F. A. Scheffler.
PROUTT, FREDERICK GEORGE,	Electrical Engineer, The Memphis Light and Power Co., 46 Tate St., Memphis, Tenn.	W. J. Jones. F. A. C. Perrine. J. B. Cahoon.
REBER, HENRY LINTON,	General Manager, Secretary and Chief Engineer, Kinloch Telephone Co., Century Building, St. Louis, Mo.	Samuel Reber. Henry Rustin. W.E.Goldsborough.
REGESTEIN, ERNEST ALBRECHT,	Instructor, Lehigh University, South Bethlehem, Pa.	W. S. Franklin. William Esty. W. L. Puffer.
REICH, WILLIAM I.,	Tester of Dynamos, Westinghouse Electric and Mfg. Co., Pittsburg; residence, 416 West St., Wilkinsburg, Pa.	C. F. Scott. F. B. Crocker C. P. Steinmetz.
REICHENBACH, FREDERICK,	Electrician, The Chesapeake and Potomac Telephone Co.; residence, 1115 Ninth St., Washington, D.C	O. A. Estes. W. H. Tapley. Philander Betts.

REID, CLARENCE ERLE,	Assistant in Electrical Engineering, Purdue University, Lafayette, Ind.	J. W. Esterline. C. P. Matthews. W.E.Goldsborough.
REYNOLDS, EDWARD LANSDALE,	Manager of Pennsylvania Sales Office; The Electric Storage Battery Co., 228 Manheim St., Germantown, Philadelphia, Pa.	Charles Blizard. Albert Taylor. R. T. E. Lozier.
RIBON, MARTIN GERMAN,	Manager, The Mexican Gas and Electric Light Co., Ltd. 7 Santa Clara, Mexico City, Mex.	C. F. Beames. A. E. Worswick. E. L. Simpson.
RIVET, ANTOINE RUSH,	Financial and Commercial Editor, Globe-Democrat; residence, 7511 Pennsylvania Ave., St. Louis, Mo.	H. H. Humphrey. W. A. Layman. Gerard Swope.
ROGERS, JOHN JAMES ROBERT CHARLES,	Electrical Engineer, Lighting Station, Yaralla Concord; residence, "Waimea" Park Road, Hurstville, Sydney, N. S. W.	J. F. Fitzmaurice. Wm. Maver, Jr. R. W. Pope.
ROYSE, WALTER A.,	Senior Partner, Royse and Batley, 20 W. Maryland St., Indianapolis, Ind.	H. B. Marsh. M. O. Southworth. A. S. Richey.
SCHMIDT, LOUIS MILTON,	Engineer Alternating Department, General Electric Co.; residence, 76 New Park St., Lynn, Mass.	F. P. Cox. Hermann Lemp. E. E. Boyer.
SCHROEDER, ALBERT VINCENT,	General Superintendent and Purchasing Agent, Springfield Electric Light and Power Co., Springfield, Ill.	H. C. Eddy. D. C. Jackson. R. C. Lanphier.
SCHWENNICKE,	Manager of Berginhe Electric Works; residence, 129 Croncuberger Str., Solingen, Germany.	H.O.F.Bindemann. W. S. Hulse. L. J. Magee.
SCOFIELD, EDWARD H.,	Electrical Engineer Twin City Rapid Transit Co., 2700 Blaisdell Ave., Minneapolis, Minn.	G. D. Shepardson. E. P. Burch. F. W. Springer.
SEAMAN, JOSEPH B.,	Chief of Testing Dept., Philadelphia Electric Co., 122 Arch St., Philadelphia, Pa.	W. C. L. Eglin. C. D. Haskins. Thomas Duncan.
SEYMOUR, WALTER ALLAN,	Salesman, Marine Engine and Machine Co., 1123 Broadway; residence, 1 West 102d St., New York City.	S. F. Weston. B. N. Jones. F. A. Scheffler.
SHARPE, FREDERICK BASSETT,	Manager The Liberty Light and Power Co., Liberty, N. Y.	W. H. MacGregor W. S. Rugg. A. Parshall.
SHERWOOD, IRVING HOWARD,	Electrical Engineer, E. P. Roberts & Co., 603 Electric Building, Cleveland, Ohio.	E. P. Roberts. Bret Harter. William Ambler.

SILVER, EARL D.,	Student, Purdue University, 1806 Arrow Ave., Indianapolis; residence, 212 North St., West Lafayette, Ind.	C. P. Matthews. J. W. Esterline. J. C. Kelsey.
SMETHHURST, WILLIAM ARTHUR,	Smethurst & Allen, North American Building, Philadelphia, Pa.; residence, Washington, D. C.	H. F. Sanville. Charles Hewitt. F. A. Wardlaw.
SPAIN, HARRY GUTHRIE,	Electrician to Post Office of Colony, Telegraph and Telephone, Georgetown, British Guiana.	William Maver, Jr. R. W. Pope. F. W. Roller.
SPENCER, FRANK BENJAMIN,	with William D. Ball, 1105 Merchants Loan and Trust Building, Chicago, Ill.	W. D. Ball. W. S. Franklin. Carl Wiler.
SPENCER, THOMAS,	General Superintendent and Designer, Helers Upton Co., 1229 Callowhill St.; residence, 922 S. St. Bernard St., Philadelphia, Pa.	Carl Hering. C. F. Scott. W. J. Hammer.
SPINNEY, LOUIS BEVIER,	Professor of Physics and Electrical Engineering, Iowa State College, Ames, Iowa.	W. S. Franklin. E. L. Nichols. B. S. Lanphear.
STEELE, J. HERBERT,	Draughtsman, Bullock Electric Mfg. Co., Cincinnati, Ohio.	W. D. Pomeroy. L. E. Bogen. B. A. Behrend.
ST. JOHN, CLAIRE P.,	Student, Polytechnic Institute; residence, 298 DeKalb Ave., Brooklyn, N. Y.	S. W. Ashe. Samuel Sheldon. Louis Dornbusch.
SYKES, FREDERICK GEORGE,	Electrical Engineer, Schenectady Street Railway and Illuminating Co., Schenectady, N. Y.	W. S. Barstow. W. L. R. Emmet. H. G. Reist.
TISCHNER, CHARLES FREDERICK,	Draughtsman Townsend & Decker; residence, 878 Lafayette Ave., Brooklyn, N. Y.	A. F. Ganz. W. E. Geyer. R. W. Pope.
TUCKER, ALBERT LINCOLN,	In charge Apparatus Sales Department, Western Electric Co., 259 So. Clinton St., Chicago; residence, 422 Greenleaf Ave., Evanston, Ill.	H. R. King. H. H. Wait. E. P. Warner.
TURPIN, MANLY CURRY,	Testing Department, General Electric Co., Schenectady, N. Y.	H. T. Hartmann. J. S. Wise, Jr. R. W. Pope.
WALKER, GEORGE LAURIE,	Engineering Apprentice, Westinghouse Electric and Mfg. Co.; residence, 7940 Madeira St., Pittsburg, Pa.	C. E. Downton. C. F. Scott. P. M. Lincoln.
WALLS, JOHN ABBET,	Assistant Engineer, Shawinigan Water and Power Co.; residence, 1724 Notre Dame St. Montreal, P. Q.	Ralph D. Mershon. W. C. Johnson J. W. Fraser.

WALSH, JAMES	Assistant Foreman Meter Department, General Electric Co.; residence, 41 Mall St., Lynn, Mass.	Richard Fleming. E. E. Boyer. N. S. Hopkins
WATSON, KENNETH,	Electrical Engineer, General Electric Co., Schenectady, N. Y.	C. P. Steinmetz. A. P. Jenks. F. W. Carter.
WELLS, ARTHUR EDWIN,	Consulting Engineer, 32 Liberty St.; residence, 718 St. Nicholas Ave., New York City.	F. A. Muschenheim H. A. Sinclair. E. S. Keefer.
WHITNEY, EDDY RUSSEL,	Engineer, General Electric Co., Lynn; residence, 7 Elmwood Terrace. Swampscott, Mass.	Richard Fleming. P. P. Cox. W. H. Pratt.
WILHOIT, FREDERIC SHELTON,	Assistant Superintendent, The Cutler-Hammer Mfg. Co.; residence, 911 State St., Milwaukee, Wis.	B. J. Arnold. T. P. Gaylord. A. W. Berresford.
WINSHIP, WALTER EDWIN,	Electrical Engineer, Gould Storage Battery Co., 25 W. 33d St.; residence, 222 W. 34th St., New York City.	A. S. Hubbard. W. W. Donaldson. F. A. C. Perrine
WOODWARD, HENRY WILMOT,	Secretary, The Cleveland Engineering Co., 1210 New England Building, Cleveland, Ohio.	William Ambler. E. P. Roberts. H. B. Coho.
WOOLLISCROFT, JOHN HAROLD,	Chief Assistant Electrical Engineer, The Sandycroft Foundry Co., Ltd., Chester, England.	N. S. Keith. William Maver, Jr R. W. Pope.

Total 140.

And the following Associates were transferred to the grade of Member:

Recommended by Board of Examiners, April 10, 1903

MERLE J. WIGHTMAN, Electrical Engineer, 150 Nassau St., New York

CHARLES O. POOLE, with Hendrie and Bolthoff, 1621 17th St., Denver, Colo.

HERBERT T. HARTMAN, Chief Engineer, Land Title Building, Philadelphia.

RAYMOND S. KELSCH, General Superintendent, Lachine Rapids Heating and Lighting Co., Montreal, Que.

PRESIDENT SCOTT:—As provided in the Constitution, the Board of Directors makes a report of the progress of the INSTITUTE during the year and of its financial affairs to the INSTITUTE at this time. The report is printed on long sheets which are now being passed about the room. This report gives a summary of the year's work of the INSTITUTE as conducted under the different committees. The report contains a reference to the development of our work through local organizations, of which some 21 are now organized. It calls attention to the fact that the increase in the membership is 44 per cent. during the fiscal year

ended May 1st. The financial report shows the INSTITUTE to be in a healthy condition. We manage to keep a small margin ahead, although the increased activities of the year in the publishing of transactions, in the publication of the monthly bulletins, and in the various operations of the committees and conduct of local organizations has materially increased the expenses. The INSTITUTE has a cash value, so to express it, of some $40,000. Most of that is in the form of the library and bonds and accounts receivable.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

REPORT OF THE BOARD OF DIRECTORS FOR THE FISCAL YEAR ENDING APRIL 30, 1903.

The Board of Directors presents herewith for the information of the INSTITUTE a report of its work during the past year, also of the financial standing of the organization.

The Annual Convention for 1902 was held at Great Barrington, Mass., June 18–22, and was generally considered the most successful ever held by the INSTITUTE, about 250 members being in attendance. The revised Standardization Report was approved by this Convention, and subsequently printed in the Transactions.

The INSTITUTE has prospered during the year; work along its established lines has been successful, and several new departments of activity have been developed. The work of the INSTITUTE is in large measure delegated to committees reporting to the Board of Direction. A brief statement regarding the work of the several standing committees and of the more important special committees affords a general view of the scope and character of the work of the INSTITUTE.

At the September meeting of the Board several of the Standing Committees were reconstituted by appointment of the incoming President.

Committee on Finance.—This Committee has kept careful guard on the finances of the INSTITUTE. At the beginning of the year it made estimates of income and obtained from the several officers and committees estimates of their probable expenses, and appropriations were then made to meet the coming demands.

Library Committee.—The Library has received numerous accessions and the work of binding, arranging and cataloguing has received due attention. The additional room available beginning at the present time will relieve the congested condition of the Library.

Committee on Papers.—This Committee has followed the plan pursued by the preceding Committee, in providing several papers upon one topic for each meeting.

Editing Committee.—This Committee finds that the increased quantity of material has made necessary the division of the bound Transactions into semi-annual instead of annual volumes. The discussions of the branch meetings add to the volume of material and to the labors of the Editing Committee. When discussions upon the same papers take place at the different branches, the same ideas are in many cases repeated, making a careful revision of the discussions necessary in order to prevent repetition while retaining all that is new and valuable.

Board of Examiners.—This Board has found the volume of its work increased owing to the larger number of applications for admission to the INSTITUTE and for transfer to full membership. During the year it has recommended 825 candidates for election to the grade of Associate and 30 Associates have been recommended for transfer.

Committee on Standardization.—The membership of this Committee was almost entirely reconstituted at the beginning of the year. The new Committee has taken up the matter of a revision of Sections 43 and 71 of the Standardization Report adopted June 20, 1902, also the extension of the Table of Sparking Distances, the Standardization of Switchboards and Materials, and the Standardization of Nomenclature.

Committee on National Electric Code.—This Committee largely reconstituted at the beginning of the year, has performed very important service in modifying the proposed rules of the National Association of Fire Underwriters with regard to high-tension circuits. The final report of the Committee has received the approval of most of the important national electrical associations, including the National Electric Light Association, the Pacific Coast Transmission Association, the Northwestern Electrical Association, and the Association of Edison Illuminating Companies.

Committee on Local Organization.—This Committee was appointed at the beginning of the year for promoting the organization of local meetings for an extension of the work of the INSTITUTE. The Committee arranged its plans in harmony with the general methods and purposes of the INSTITUTE, and announced general plans for the inauguration of meetings without much formality of organization. Local branches have been formed in several cities, and also in a number of Universities and Technical schools, in some cases under the direct supervision of the Instructor and in other cases in connection with an engineering society among the students. Local branches among INSTITUTE members are in some places conducted independently of other organizations; in other cases they are held in connection with a local engineering club or society. During the year local branches have been organized at the following places:

Allegheny, Pa. [Western University of Pennsylvania]; Ames, Iowa [Iowa State College]; Bethlehem, Pa. [Lehigh University]; Boston, Mass. [Massachusetts Institute of Technology and local members]; Cincinnati, Ohio; Columbia, Mo. [University of Missouri]; Columbus, Ohio [Ohio State University]; Denver, Colo.; Ithaca, N.Y. [Cornell University]; Lafayette, Ind. [Purdue University]; Madison, Wis. [University of Wisconsin]; Philadelphia, Pa.; Pittsburg, Pa.; Schenectady, N Y. [Union University and local members]; St. Louis, Mo.; State College, Pa. [Pennsylvania State College]; Urbana, Ill. [University of Illinois]; Washington, D. C. [Columbian University and local members].

The local organizations in Chicago and in Minneapolis, the latter in connection with the University of Minnesota, which have been in existence for some time, have taken on renewed activity during the present year. The weak point in national organization which has long been recognized, is the inability of a scattered membership to participate in society meetings. This difficulty has been in large measure overcome by establishing local branch meetings at which the papers and discussions presented at the general meeting in New York are read in the various local branches. The result of the local branches as a stimulus to the growth of membership, is shown by the following table:

	Membership Nov. 1, 1902	Membership and applications now on file, 1903	Gain.
Chicago	85	139	54
Pittsburg	63	115	52
Philadelphia	65	84	19
Boston	75	164	89
Denver	6	30	24
Cincinnati	19	44	25
Schenectady	54	105	51
Columbus, Ohio	6	15	9
St. Louis	18	41	23
	391	737	346

Students of the Institute.—Closely related to the work of the local branches is the action of the Board of Directors, granting privileges to students who are pursuing electrical studies by which they may obtain the monthly Transactions of the INSTITUTE and other privileges at small expense.

Committee on Theses.—The Board of Directors by resolution invites the heads of the electrical engineering departments in educational institutions in which local INSTITUTE meetings are held to select the thesis of each year's graduating class that is of superior merit. The theses so submitted are referred to the INSTITUTE Committee on Theses which may select and recommend to the Board for publication those of superior excellence. This will give a stimulus to electrical students and will be a satisfactory means of giving recognition and publicity to that which is of merit.

Committee on Engineering Data.—After careful consideration of the matter, the Board has established a Committee on Engineering Data for the purpose of collecting and publishing data of use in the electrical engineering profession. This Committee is proposed as a permanent Committee and its grade of work will be on a par in its importance and dignity with that of the Committee on Standardization.

Transmission Committee.—This Committee was appointed at the beginning of the year for collecting data respecting the present practice in electric transmission at high voltage, and of presenting a report in such form as to be of immediate value to electrical engineers. In addition to the collection of data this Committee has selected a number of pertinent topics for discussion and has prepared short papers as introductions to general discussions by the members.

Committee on Membership.—This Committee was appointed at the beginning of the year for the puprose of increasing the membership principally through the coöperation of individual members. The Committee has presented to the members from time to time the desirability of bringing together those who may assist the INSTITUTE, as well as those who may profit by being connected with it. The members have acted upon the suggestion of the Committee, and a notable increase in membership is the result.

Committee on Affiliated Societies.—This Committee has been appointed

for investigating the relations which the INSTITUTE should bear to other organizations, such as other electrical bodies, local engineering societies in connection with local branches of the INSTITUTE and other engineering bodies. This Committee enters upon a large field which may be of the greatest importance to the development of the electrical engineering profession.

John Fritz Medal.—The INSTITUTE has coöperated with the other three general engineering societies in the establishment of the John Fritz medal, and in appointing members of the jury for the award of the medal.

Committee on Universal Exposition at St. Louis.—The Board has by the recommendation of a Committee appointed to consider the relations which the INSTITUTE should sustain to the Exposition and the Engineering Congresses to be held in connection therewith, a Committee on Exhibits. This Committee will have under its direction the collection of an historical and evolutionary exhibit. The Board expects to so arrange that the INSTITUTE will take an active part in the Congresses to be held at the time of the Exposition.

Institution of Electrical Engineers.—The invitation of this INSTITUTE to the Institution of Electrical Engineers to visit America in 1904, and participate in a joint meeting, has been accepted. It is expected that arrangements will be made to hold the joint meeting in St. Louis in connection with the Engineering Congresses.

Union Engineering Building.—The Board has received the letter of Mr. Andrew Carnegie stating that he will give to the four national engineering societies—Civil, Mechanical, Mining and Electrical—and the Engineers' Club, one million dollars for a Union Building. The Board at its special meeting on May 7th, adopted resolutions endorsing the project and certain provisional plans of procedure, and appointed a committee to report to the Board the form of resolution which it should adopt in common with other bodies in order to participate in the Union Building. The final action of the Board of Directors and its recommendation to the INSTITUTE is contained in a separate report.

Monthly Announcement.—The meeting notices to members have taken the form of small pamphlets containing statements regarding the general meetings and the meetings of the various local branches. The Announcement also contains a Secretary's Bulletin and statement of the work of the various Committees, also any other matters of general importance. The list of applications for admission is included in the pamphlet. This form of Announcement keeps the members in more intimate relation to the INSTITUTE work, and is believed to be valuable in awakening and sustaining interest therein.

Reception Committee.—The Reception Committee has been in charge of the unofficial dinners which have been enjoyable social features preceding the monthly meetings. The success of the Library Dinner on February 9th is due to the efforts of this Committee.

Institute Headquarters.—Owing to the growth of the Library and the increase of the general work of the INSTITUTE, it has been found necessary to rent additional space, and on May 1st, the entire seventh floor of the White Building, 95 Liberty Street, was leased. Nearly one-half of this will be occupied by the Library and the remainder by the publication clerical and other departments.

Membership.—The total membership at the close of last year's report, was 1,549, classified as follows:

Honorary Members		2
Members		405
Associates		1,142
Total May 1, 1902		1,549
Elected prior to May 1, 1902, and since qualified		16
Elected May 1, 1902, to April 30 1903, and qualified		695
Restored to Membership		1
		2,261
Total Deaths	9	
" Resignations	12	
Dropped as delinquents	11	32
Grand total, Apr. 30, 1903		2,229

The membership Apr. 30, 1903, was classified as follows:

Honorary Members	2
Members	417
Associates	1,810
Total	2,229

A list of Associates elected during the year accompanies this report. The gain in membership during the year is 680, an increase of 44 per cent. As there are now applications pending and Associates elected but not yet qualified to the number of 391, there is an immediate prospective total of 2,620 members.

Associates Elected.—The Associates elected during the year, May 1, 1902, to April 30, 1903, and their present status is as follows:

Qualified and now associates	695
Died before qualification	1
Elections cancelled	4
Not qualified on Apr. 30	165
Total elections	865

Resignations.—Resignations have been received and accepted during the year from the following members and associates who were in good standing:

Members.—Brown Ayres, W. E. Geyer, Henry Jackson.

Associates.—Frank Broili, Harry A. Gillis, F. A. Greenwood, A. F. McKissick, H. N. Sweet, Walter Rutherford, H. Schreiter, J. C. Finney, Paul Bonynge.

Deaths.—There have been the following deaths during the year:

Members.—Charles T. Child.

Associates.—Henry Norton, E. Rathenau, W. F. D. Crane, Max T. Steinle, F. J. Folk, E. A. Darling, I. D. Parsons, Sidney H. Short.

Financial Report.—The reports of the Secretary and Treasurer show in detail the financial standing of the INSTITUTE at the close of the fiscal year, together with an itemized statement of the receipts and disbursements during the entire year.

FINANCIAL STATEMENT FOR APRIL 30, 1903.

ASSETS AND LIABILITIES.

ASSETS.		*LIABILITIES.*	
Cash	2,006.75	*Library Fund	787.93
U. S. Bonds, Market value	16,285.00	Carnegie Fund	4,643.60
Library	9,436.75	Building Fund	1,100.00
Transactions (volumes)	2,957.50	Compounded Membership Fund	4,200.00
Office Furniture and Fittings	495.30	Reserve Fund	10,556.68
Badges	154.50	Surplus	19,311.48
Catalogue Type and Cases	125.00		
Congress Books	231.25	*Not including a donation of $1,100 by one member and about $1,000 by another still in the hands of Library Committee.	
Accounts Receivable	8,407.64		
" " Secretary's Petty Cash	500.00		
	$40,599.69		$40,599.69

RECEIPTS AND DISBURSEMENTS.

RECEIPTS.		*DISBURSEMENTS*	
Entrance Fees	$ 3,305.00	Stenography	697.00
Current Dues	17,583.95	Stationery and Printing	2,143.15
Past Dues	1,168.47	Postage	1,543.50
Advance Dues	740.59	Express	346.54
Life Membership Fund	600.00	Badges	619.93
Transactions Sales	1,752.24	Expenses General	667.95
" Subscriptions	463.63	Certificates	93.90
Binding	64.63	Office Fittings	239.60
Advertising	1,685.51	Salaries	5,350.41
Electrotyping and Engraving	23.67	Engraving and Electrotyping	1,778.93
Badges	783.50	Publishing Transactions	7,254.16
Congress Books	16.10	Rent	1,088.04
Postage	1.57	Advertising	804.88
Meeting Expenses	5.00	Binding	577.71
Interest	496.36	Meeting Expenses	1,208.43
Library Donation	1,028.23	Branch Meetings	40.65
Library Volumes	242.80	Office Expenses	154.27
Certificates	220.00	Library Expenses	3,994.62
		Library Fixtures	330.00
		Students	21.00
		Balance	621.58
	$30,181.25		$30,181.25

The total receipts for 1903, exclusive of donations to Library Fund, were in excess of 1902 ..... $8,497.83
The total disbursements for 1903, were in excess of 1902 9,262.61
Due from Members account of entrance fees and dues .. 7,344.07

Total Cash Receipts	$30,181.25	
Total Cash Disbursements	29,559.67	
		621.58

Property on hand according to Inventory May 1, 1903:

Office Furniture and Fittings	495.30	
Badges	154.50	
Transactions	2,957.50	
Congress Books	231.25	
Printing Material	125.00	
Library. Valuation for inventory purposes	9 436.75	
		$13,400.30

TOTAL NET ASSETS.

Cash	$2,006.75	
" Secretary Petty Cash	500.00	
U. S. Bonds, Market value	16,285.00	
Inventory (as above)	13,400.30	
		$32,192.05
Total Assets last year		30,192.05
Increase		$1,971.81

PROPERTY PURCHASED DURING THE YEAR.

(Reported as directed by the Constitution.)

Office Furniture	$207.00
Typewriter	100.00
Mailing Machine	19.60
Transactions Volumes	324.00
	$650.80

Respectfully submitted,

RALPH W. POPE,
Secretary.

TREASURER'S REPORT.

FROM APRIL 30, 1902, TO MAY 1, 1903.

GEORGE A. HAMILTON, TREASURER, in Account with
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Dr.

Balance from April 30, 1902	$ 1,385.17
Received from Secretary, May 1, 1902, to May 1, 1903	30,181.25
	$31,566.42

Cr.

Disbursements May 1, 1902, to April 30, 1903, on warrants No. 1556 to No. 1832	$29,559.67
Balance to New Account May 1, 1903	2,006.75
	$31,566.42

Respectfully submitted,

GEO. A. HAMILTON,
Treasurer.

The election of officers for the next year began with the sending out of nomination ballots in February last. The ballots which have been received recently have been turned over to a board of tellers, who have made out their report and it will be now presented. The officers elected now will take office on the fourth Friday of next September. Mr. F. W. Roller, chairman of the Committee of Tellers, has placed the report of the committee in the hands of the Secretary, who will now announce the result.

SECRETARY POPE:—The result of the ballot for officers as follows: For President, B. J. Arnold, 705 votes; 8 scattering; for Vice-Presidents, Calvin W. Rice, 687; W. S. Barstow, 677; R. D. Mershon, 663; with others scattering; for Managers, Samuel Sheldon, 683; A. H. Armstrong, 672; W. C. L. Eglin, 644; G. F. Sever, 642, with a considerable number of scattering votes, the highest of which is 16 for A. E. Kennelly; for Treasurer, G. A. Hamilton, 713; for Secretary, R. W. Pope, 712; T. C. Martin, 1; total ballots, 764, of which 51 were defective.

PRESIDENT SCOTT:—The Chair declares that the following gentlemen have been elected the officers of the INSTITUTE for the ensuing year: President, B. J. Arnold; Vice-Presidents, C. W. Rice, W. S. Bartsow, R. D. Mershon; Managers, Samuel Sheldon, A. H. Armstrong, W. C. L. Eglin, G. F. Sever; Treasurer G. A. Hamilton: Secretary, R. W. Pope.

The Secretary suggests that the report of the Board of Directors presented in outline by the Chair and now before you in written form, should be acted upon. If there is any question to be asked or any action to be taken on the report, now is the time to take it.

UNION ENGINEERING BUILDING.

The first announcement before the INSTITUTE as a body of the progress which has been made toward a building for its uses can be made this evening. There has been for many years, since the foundation of the INSTITUTE, a conviction among its leading

members that it needed a building adequate for its present and future needs. There has been also for years a sentiment, sometimes fairly prominent, at other times seemingly almost forgotten, calling for a Union Engineering Building, in which the several large engineering societies could be housed together. We have been in a way acting on that principle ourselves, as we have been coming here to the house of the American Society of Mechanical Engineers, our brother engineers, and in common with them we appreciate the need of a larger house. These sentiments have been growing and have come to the attention from time to time of Mr. Carnegie. The matter of an engineering building has been discussed more or less informally in the past, so I think there has been in the mind of Mr. Carnegie a growing sentiment, a growing ideal in this direction, and he has probably been awaiting the time when the occasion would seem to be opportune, and when the conditions would be ripe for the materialization of this idea. Through the efforts of Mr. Martin, whom Mr. Carnegie designated as "irrepressible," we had the very great privilege and pleasure of entertaining Mr. Carnegie at our Library dinner on the 9th of last February. He seemed to enjoy himself that evening, entering into the spirit of things, and recognizing that he was among friends. He recalled the time when he was an electrician himself, in a cellar in Pittsburg. He saw how electricians had developed and grown, saw their influence, saw their possibilities, and it seems that he recognized that possibly now the time had come when something could be done. So he called before him two of the electricians who were at the dinner, and they met him the next day to have a friendly chat on the matter.

I need not tell the story. It has been sent to you in printed form in order that, as soon as the matter could properly be made public, you would be fully informed with regard to it. A meeting of three representatives from each society in conference committee has evolved a set of resolutions to be formally presented to the several bodies for action. These resolutions were brought before the Board of Directors of the INSTITUTE this afternoon, and with a few slight changes were passed as follows:

RESOLUTIONS PASSED BY THE BOARD OF DIRECTORS OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, MAY 19, 1903, WITH REGARD TO A UNION ENGINEERING BUILDING.

(1) *Resolved*, that the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS unite with the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, and The Engineers' Club or any of them, for the purpose of accepting the sum of $1,000,000, as a gift from Mr. Andrew Carnegie, for the purpose of erecting suitable buildings for occupancy by the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, the AMERICAN INSTITUTE OF

ELECTRICAL ENGINEERS and The Engineers' Club, on the sites secured for that purpose on the north side of 39th Street and south side of 40th Street, west of Fifth Avenue, in the City of New York, in the State of New York.

(2) *And Resolved Further*, that the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, has a very high appreciation of this generous gift of Mr. Andrew Carnegie, and this additional evidence of his recognition of the engineering profession and his deep interest in the welfare of the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS and The Engineers' Club.

(3) *And Resolved Further*, that a site on the north side of 39th Street shall be purchased and held by trustees, or otherwise as shall be determined by the joint committee hereinafter mentioned for the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers and the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, or by such of them as shall vote in favor of coming into this enterprise.

(4) *And Resolved Further*, that a joint committee shall be created to be composed of three members of each organization that shall unite in accepting said gift of $1,000,000 from Mr. Andrew Carnegie; and that the governing body of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS shall elect three members of this organization to represent it on and be members of such joint committee; and that the governing body of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS shall have the right and power to remove any member of such joint committee who shall be elected by it and to elect any member of this organization to fill any vacancy that shall occur in such joint committee by reason of the death, resignation, refusal to act or removal of any member who shall have been elected by the governing body of this organization as a member of such joint committee.

(5) *And Resolved Further*, that the character and internal arrangement of the building to be erected on the site on 39th Street shall be determined upon by the affirmative vote of at least two-thirds of all of such of the members of said joint committee as shall represent the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers and the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS or such of them as shall vote in favor of coming into this enterprise, on such joint committee; that the character and internal arrangement of the club building to be erected on the site on 40th Street, shall be determined upon by the affirmative vote of all of the three members of such joint committee who shall represent The Engineers' Club on such joint committee; and that the apportionment of funds between the two buildings shall be determined by an affirmative vote of two-thirds of the entire joint committee.

(6) *And Resolved Further*, that said joint committee shall, by the affirmative vote of at least two-thirds of all of the members thereto, select and employ an architect and such consulting engineers as may be necessary to prepare the plans and specifications for the building to be erected on the site on 39th Street and for the club building to be erected on the site on 40th Street; and shall also obtain proposals for the erection of both of such buildings; and shall have power to make and enter into such con-

tract or contracts as shall be approved and authorized by the affirmative vote of at least two-thirds of all of the members of said joint committee, for the erection of both of such buildings; and shall have charge of the erection of both of such buildings.

(7) *And Resolved Further*, that said joint committee shall continue in existence until all of the purpose set forth in these resolutions shall have been fully accomplished.

By direction of the Board, the committee in charge of affairs has submitted these resolutions to legal counsel and has the opinion of Paul D. Cravath, of Guthrie, Cravath & Henderson, as follows: "I return resolutions, which seem to me to be in proper form. They have the important merit of leaving the committee free to work out details of the proposed plan without being hampered by definite instructions."

The Board of Directors at its meeting this afternoon, in addition to adopting the resolutions, appointed as the permanent committee to represent the INSTITUTE, the present President of the INSTITUTE, the President-elect, Mr. Arnold, and Dr. Wheeler.

That is the history of the building plan up to date.

The attitude and views of some of the members of the INSTITUTE, among whom are many of our past Presidents, are before us in the form of a few letters which I am sure you will be pleased to hear. I will ask the Secretary to read some of these letters.

Secretary Pope read the following:

"ORANGE, N. J., May 18, 1903.

CHARLES F. SCOTT,
President AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS,
New York City.

DEAR MR. SCOTT:—I am delighted to note the sequel of the INSTITUTE Library Dinner which I had the pleasure of attending last February, and am heartily glad to be able to congratulate you on the generous gift of Mr. Carnegie of one million dollars to the INSTITUTE and its sister societies. I have the greater pleasure, in this benefaction to the society, because it comes from one of ourselves, who began at the key and has shown himself so worthy of the great wealth that has come to him since he was a humble telegrapher.

I am convinced that all the societies concerned will feel it their duty to unite in the disposing of this gift so as to render it of the utmost value and profit to the professions they represent and to the arts and sciences in general.

Faithfully yours,
THOMAS A. EDISON."

"CAMBRIDGE, MASS., May 14, 1903.

MESSRS. CHAS. F. SCOTT and T. C. MARTIN,
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS,
New York City.

GENTLEMEN:—It gives me great pleasure to learn that it is proposed, with the generous aid of a world-widely known man, whose success has been achieved in connection with engineering development, to erect a useful and enduring structure of steel and stone that shall attest and perpetuate the essential unity of all engineers and engineering in subjugating nature to the rising needs of humanity.

It seems to me that no more valuable endowment could be made for engineering than that which will harmonize and unite the various engineering societies, bringing these bodies into one building, and building them into one body. It would bring into closer coöperation the branches of that guild whose past industry has made possible the greater coöperation and the grandest civilization that the world has already won.

I sincerely hope that this proposition may duly assume outline on paper and speedy realization in stone. I regard it not merely as a lasting benefit to engineers, but also through their labors, and the work that they will carry on in the Union Engineering Building, as a distinct gain to all the nations of the world.

With every good wish for the success of this project, I remain, gentlemen,

Yours very sincerely,

A. E. KENNELLY."

"PHILADELPHIA, PA., May 18, 1903.

MESSRS. CHAS. F. SCOTT and T. C. MARTIN,
New York City.

DEAR SIRS:—Just two years ago a committee of this INSTITUTE held a conference with Mr. Andrew Carnegie concerning the Clark library, the result of which was that Mr. Carnegie, with his world-renowned generosity, presented the INSTITUTE with a sum of money equal to the original cost of the library, to be used for its maintenance. The subject of a home for the INSTITUTE and its library was also approached at that time, and the parting words of Mr. Carnegie to our committee were to the effect that as soon as we felt able to maintain a home we should call to see him again.

From his recent magnificent offer, Mr. Carnegie seems to consider that we are now able to maintain a home, even a much larger and more magnificent one than was contemplated two years ago. That he did not over estimate our abilities to do this, is the belief of those of our members who have been most active in this effort to provide the INSTITUTE with a much-needed home. It therefore becomes the duty of every loyal member who has the interest of the INSTITUTE at heart to assist our able and energetic committee and President in every possible way, in order that the grand project which they have planned may be successfully carried out.

Those of our members whose fortunes have been made in the electrical industry and profession now have an opportunity to follow the generous example set to Mr. Carnegie by recognizing in a substantial way the institution which has been such a potent factor in the marvelous development of an industry which has brought fortunes to many.

This INSTITUTE is now recognized to be of national importance, and during the past few years its reputation and standing is beginning to be recognized abroad. It has no rival in its branch of engineering in this country. National questions are referred to it and its opinion on international matters is respected.

Although the youngest of the national engineering societies, it has been the most active in the efforts to realize that long-cherished dream of so many engineers, a Union Engineering Building in the Metropolis of our country. We should therefore not be the last to assure Mr. Carnegie that he has not overestimated our abilities to maintain the magnificent home, which he has so generously offered us.

Very respectfully yours,

CARL HERING,
Past-President."

"NEW YORK, May 12, 1903.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS,
New York City.

GENTLEMEN:—I certainly think that it will be of the greatest advantage to the work of the INSTITUTE if the plan respecting a Union Engineering Building can be carried out. The INSTITUTE must certainly have a place for housing its library and nothing need be said about the advantages of

bringing together the libraries of the different engineering societies. The advantages of such a union are self-evident. While my duties at the Cooper Union for the last eight years have so occupied my evenings that I have not been able to attend many of the meetings of the INSTITUTE, I have felt the keenest interest in its work, and I know that the papers that have been read and the discussions that have followed upon various subjects have helped very greatly to advance the interests of the electrical art, and if a building can be secured where the INSTITUTE can have permanent quarters in connection with the other Engineering Societies I am sure it will increase greatly the efficiency, not only of its work, but of that of the other societies also.

I hope nothing will prevent a favorable action upon this matter.

Yours very truly,

WM. A. ANTHONY."

PRESIDENT SCOTT:—There is one phase of the building matter which I did not refer to in my remarks a few moments ago. When on the first afternoon the general subject was under discussion with Mr. Carnegie and we were talking over the whole proposition, and he was concerned where we could get the land and what it would cost, we presented to him an outline of the present status of the various bodies; their financial standing, their membership, income, what they were now paying in rents, etc., and he at once said, "Why, you are able to carry yourselves; if you can provide the land for the building and take care of it, I will give the building." He seemed to think that providing the building was the easy part, and the other was the hard part. In the aggregate the various organizations concerned are able to carry the land very well. We Electrical Engineers are most of us young men starting out in life, not like the members of the older societies, who have made their fortunes. Consequently, our Institution is not in the financial position which the others are, and when it has now come time to go in and take our share in this matter we find ourselves in a different position from the other societies.

The estimates of the committee as reported to the Board, and which in general receive the sanction of the Board, though the Board did not go into the matter in detail, shows in a general way that the INSTITUTE should have a fund of about $200,000 to put it in good condition to assume its fair part in this new enterprise. There are various ways in which this money could be secured, in fact it is quite possible that in four or five years from now the INSTITUTE will be as able to pay the interest on bonds to provide for the land as it has been in the past to pay rentals. But that is not what we would like to do. The INSTITUTE is growing and developing; its committees go to the limit in expending the appropriations; nearly every committee could enlarge its work. Our new committee on local organizations, which is developing the work of the INSTITUTE throughout the country so finely, calls for an expenditure of more funds for the printing of Transactions and the like, and for the local running expenses of the several organizations. That is but one example. Every way we turn our work is costing more and more as we

expand, and make the work more efficient, so that what we ought to have is such a provision for the land as well as the building which will enable the current income of the INSTITUTE to be used for its current expenses and its technical work.

We have made this suggestion, which I have just indicated to you, to a few members and we are pleased to-night to be able to announce a few subscriptions as a beginning to what we hope will continue for some time in the future to be a growing fund.

We have the following letter from a past-President of the INSTITUTE:

"NEW YORK, MAY 11, 1903.

T. C. MARTIN, ESQ.,
Committee on Union Engineering Building,
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

MY DEAR MR. MARTIN:—I wish to add a word of congratulation on the possibilities of development assured the INSTITUTE by the magnificent offering of Mr. Carnegie for the erection of a Union Engineering Building in connection with the Engineers Club.

Not many years have passed since the inauguration of our society, but already the self-sacrificing labors and constant efforts of its officers, among whom none have been more faithful to its interests than yourself, coupled with the unparalleled growth in the various branches of the electrical industry have brought the INSTITUTE to a position where it must necessarily be more commanding in its engineering influence.

With its growth has come the greater need of the highest professional equipment on the part of those composing its membership and dominating its councils.

The work of the universities and technical schools, and the great responsibilities now involved in electrical undertakings, requires the highest professional standard. The successful engineer in electrical work must no longer be simply an electrical engineer, but coupled with his specific knowledge must be mechanical and civil engineering attainments of high order. On account of the diversity of work few can be expert at all branches, but they must at least have sufficient knowledge to fairly guide them in enterprises requiring the highest skill in every branch.

These facts make it all the more essential that instead of the engineering societies being individualized they should be brought in closer touch so that opportunities may exist for each to become better acquainted with the other, and to gather by intuition, as well as by specific instruction, completer knowledge of engineering practices, and especially to have the advantage that technical libraries housed and technical papers given in a common building may grant.

While it is perhaps natural that such a building shall have as its principal attraction the technical libraries of the different societies, which should, under suitable restrictions, be accessible to all members, it would seem proper that it might also have in its equipment as a source of inspiration and instruction, a collection of models of the original apparatus illustrative of important departures in engineering practices.

As a member and a past-President of the INSTITUTE, I am in hearty accord with the general plan which has been proposed for a building to be occupied as a common home, and I will gladly bear some portion of the burden which will fall upon our particular INSTITUTE, to which end I take pleasure in authorizing you to say that in the event of the proposed plan maturing I will subscribe $2,000 for such fund and under such conditions as may be established in accordance with the general circular of May 9.

Sincerely yours,

FRANK J. SPRAGUE."

PRESIDENT SCOTT:—We have a letter from Prof. Elihu Thomson, which the Secretary will read. In addition to this letter, the Secretary also has a letter from Prof. Thomson making a contribution of $5,000 to the building fund.

"SWAMPSCOTT, MASS., May 16, 1903.

MESSRS. CHAS. F. SCOTT and T. C. MARTIN,

GENTLEMEN:—Just fourteen years ago I had the honor and duty of addressing, as the representative and President of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, a unique gathering in the Guildhall, London. There were present the leading engineers of Great Britain and their guests, the visiting American Engineering societies, altogether about six hundred. Among these the electrical engineers formed but a small percentage. Our art was young and our INSTITUTE very young. Our art is still young and so is our INSTITUTE compared with the other engineering bodies. But its record of creditable work is not excelled. There is in it plenty to awaken our members to the importance of assisting in all possible ways in laying the new foundation upon which the future of the INSTITUTE will rest.

It is not conceivable that any member can fail to be deeply interested in the new possibilities and opportunities which arise out of the munificent offer of Mr. Carnegie. By his most generous gift he has shown his own deep interest in the work and in the future coöperation of our chief engineering bodies. The membership of those bodies now have the duty of seeing to it that the gift is largely used and in a way to redound forever to the credit of American engineers.

There is no need to dwell upon the importance of the work of our INSTITUTE in the past. Who can doubt that with the enormously enlarged opportunities now to be afforded that there will be a great extension of its usefulness in the future.

Respectfully yours,

ELIHU THOMSON."

PRESIDENT SCOTT:—We will now pass from the list of our past-Presidents—every letter which has been read, except the first, from Mr. Edison, has been from a past-President—to the roll of our members.

Secretary Pope read the following letter:

"NEW YORK, May 13, 1903.

MR. CHARLES F. SCOTT,
Pittsburg, Pa.

MY DEAR MR. SCOTT:—The proposed Union Engineering Building impresses me as being a magnificent project and all of the engineering fraternities are certainly indebted to Mr. Carnegie for his liberal offer. It will give me great pleasure indeed to contribute toward the portion of the fund for land which must be raised by the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. Toward this I shall be very glad to send you at any time the money is required a check for $1,000. In addition to this, I shall be very pleased at any time to confer with either Mr. Rice, Mr. Martin or yourself, regarding the matter which has been referred to this committee, and it will be a pleasure to me to render any assistance possible.

Wishing you great success in your endeavors, I remain,

Very sincerely yours.

J. G. WHITE."

PRESIDENT SCOTT:—I have made a memorandum on the bottom of this letter from Mr. White as follows: May 16, 1903. Mr. White stated to me that if the whole of the amount necessary be raised by the INSTITUTE by subscription he would increase his contribution by $1,500, making a total of $2,500.

In addition to the individual contributions which have been mentioned, it is expected that a number of the electrical companies will take part in this enterprise. We have been consulting with gentlemen connected with a few of them. We have re-

ceived encouraging words in several quarters. Arrangements of that kind naturally take a little time for consummation, so that to-night only one can be announced. Mr. Osborne, the Fourth Vice-President of the Westinghouse Electric & Manufacturing Company, authorizes me to state that, with the expectation that other companies will join in the enterprise, the Westinghouse Company will contribute $5,000 to the building fund. We have here in the very beginning, a number of substantial contributions toward this end. We want to awaken and maintain a live interest in this subject on the part of all who should be interested in it. It is not a matter of begging for assistance, but it is presenting the matter on its merits and expecting recognition of those merits. I think we are justified in taking a few minutes now for an expression of opinion on this building scheme by the gentlemen who are present here this evening. As we have one of our donors here this evening, I am going to ask Mr. White to say a word, and to stand up a moment so that we can get a sight of him.

MR. J. G. WHITE:—I have not much to add to the remarks contained in my letter which was read a few moments ago. I should particularly like to see the entire amount which must be provided by the INSTITUTE, raised by contributions of members and friends, and none of it raised by mortgage on the land which the INSTITUTE must acquire. I understand that it has been suggested by Mr. Carnegie himself that part of the necessary money may be secured by such mortgage. It seems to me that it is possible for the INSTITUTE to secure sufficient funds to pay for its portion of the necessary land without resorting to such mortgage loan. With contributions such as just announced from the Westinghouse Company, Prof. Thompson and others, and with the many contributions which will undoubtedly be available, it ought to be possible for the INSTITUTE to raise all the funds needed.

If this cannot be done immediately, we must resort to a loan, which should have a sinking fund provision, by which the amounts borrowed will gradually be repaid leaving the land of the INSTITUTE free and clear of indebtedness.

PRESIDENT SCOTT:—We would like to hear from Mr. Martin, one of our past-Presidents, who began work as President a long while ago and never stopped.

MR. MARTIN:—I am obliged to you for calling upon me, Mr. President, but I think there has been enough said about me. I want to do a little more work, that is all.

PRESIDENT SCOTT:—Mr. B. J. Arnold, of Chicago, has just been ushered into this work this afternoon, being put on the committee to represent the INSTITUTE, and I can assure him there is work ahead for him.

MR. ARNOLD:—I think the best speech I can make to-night will be to remain absolutely silent for I can show better by my actions during my term of office than my words would express to-night what I shall do toward making the venture now considered a complete success. I will do all I can to that end.

MR. MARTIN:—I would suggest, Mr. President, that we voice our gratitude to Mr. Carnegie; that we send him a cable message of gratitude.

PRESIDENT SCOTT:—The Board of Directors this afternoon authorized the sending of a cable message of thanks to Mr. Carnegie and asked that Mr. Mullin confer with Mr. Martin to draft a suitable cablegram. As Mr. Mullin does not appear to be present, it still looks as if all the work will fall on Mr. Martin.

There is one man who ought to be here to-night as he is one of a number who have been promoters of the building idea, and to whom a great deal of credit is due. He has been chairman of our building committee which has been planning and hoping for a long time; but all at once the ideal has culminated in a great good fortune which is now ours. The man to whom we are so much indebted is Mr. Calvin W. Rice, who with the President, was summoned by Mr. Carnegie on the day after our annual dinner last February.

The Board of Directors asks that the INSTITUTE pass the following resolution: The AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS at its annual meeting endorses the action of its Board of Directors in the adoption of resolutions looking to the acceptance by the INSTITUTE of the generous gift of Mr. Andrew Carnegie in his letter of February 14, 1903, giving one million dollars for the purpose of a Union building, the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS and the Engineers Club.

Mr. J. G. White moved the adoption of the resolution, and the motion was unanimously carried.

MR. MARTIN:—Mr. President, the cablegram which I have drafted to be sent to Mr. Carnegie is as follows:

ANDREW CARNEGIE,
SKIBO CASTLE, SCOTLAND.

The AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, in annual meeting assembled, accepts with gratitude and sends you hearty thanks for its share of your generous gift of the Union Engineering Building, and pledges its best efforts to render your great benefaction useful in the promotion of electrical and other engineering arts and sciences.

Mr. Dunn moved that the cablegram be forwarded. Motion carried.

SECRETARY POPE:—The committee on proxies reports a total of 270 proxies. Those holding the principal proxies are R. W. Pope, 136; B. J. Arnold, 31; C. F. Scott, 15; R. T. Lozier, 12; blanks, 21; rest scattering. A quorum of 159 is necessary. 186 proxies are held by gentlemen who are present, so that there is a quorum present.

PRESIDENT SCOTT:—If the proxies are not called for, the vote on the resolution just passed will stand.

SECRETARY POPE:—In regard to the annual report submitted by the Board of Directors, I would say the contribution of Mr. C. O. Mailloux, of about $1,100 to the library, which was reported about a month ago, is still in the hands of the secretary, owing to a question in regard to its proper investment. It does not appear in the report. There is also about the same amount which has been contributed for books by another gentleman, which is not yet included in the report. The valuation of the library at $9,436.75 is simply an inventory value at $1 per volume. The Library Committee is now making a report which will give the appraised value more in accordance with the actual value of the books.

A paper read at the 177th Meeting of the American Institute of Electrical Engineers New York, May 19 1903.

THE EXPERIMENTAL BASIS FOR THE THEORY OF THE REGULATION OF ALTERNATORS.

BY B. A. BEHREND.‡

The presentation of this paper has been undertaken with a view to supplying the Committee on Standardization with data to enable them to draw up rules for the determination of voltage regulation, as Section 71 of the INSTITUTE rules is, by no means, in accordance with fact and observation.

Many papers have been published by various authors on the theory of voltage regulation in alternating current machines, but their writers have been sadly in the dark as to the actual facts which a complete theory has to explain. This state of affairs is perfectly natural, as experiments on large modern machines are extremely difficult and costly, and few men have either the patience or the opportunity to carry out series of measurements which can be used as a foundation upon which the theory of regulation can be built. A theory which is not supported by facts is worse than none, and yet without theory it is impossible to design rationally and economically any kind of apparatus. Designers of alternating current machinery who ten years ago began to develop for themselves the necessary theoretical basis for their designs, will, no doubt, appreciate the difficulties which they had in obtaining a clear view of the many conditions to be taken into account in designing alternating current generators

‡ Papers by the Author on "Regulation in Alternators."

Elektrotechnische Zeitschrift, Berlin, 1897, pages 715 and 771. Letters on "Armature Reaction and Potential Drop in Alternators."

1899, No. 48, "On Potential Drop in Alternating Current Generators."

L'Eclairage Electrique, Paris, 1900, p. 140, "Sur le Calcul des Alternateurs."

Electrical World and Engineer, New York, 1900, January 20, 27 and February 3. "The Factors which Determine the Design of Single-phase and Multiphase Alternators."

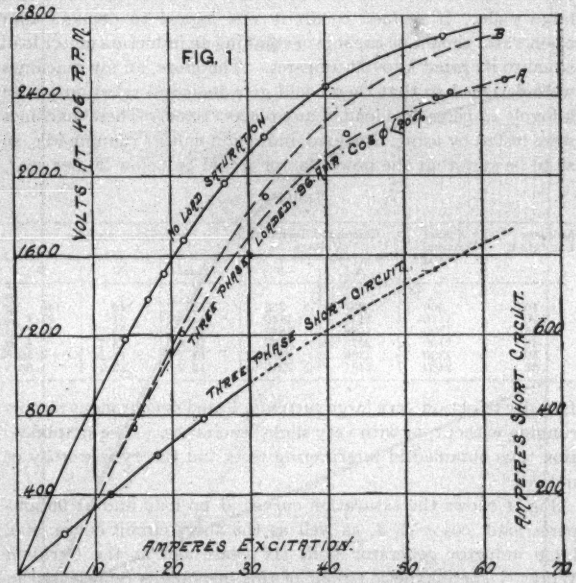
and synchronous motors. And no doubt they will remember that the greatest difficulty which they encountered was the question of how to determine the inductive drop in the armature.

The subject matter of this paper is to supply an array of experimental data obtained on the most modern designs of alternating current generators. A somewhat empirical theory is given in this paper, which satisfactorily explains quantitatively and qualitatively the observed results; but no attempt is made in this theory to take into consideration the many varying factors that would naturally have to be introduced into a complete theory of the phenomena of regulation.

The presentation of this paper has been undertaken, partly, with a view to supplying the Committee on Standardization with data to enable them to draw up correct rules for the determination of voltage regulation, as Section 71 of the INSTITUTE rules is, by no means, in accordance with fact and observation. The matter being of extreme importance, the duty devolves upon the designing engineers, who have accumulated experimental evidence, to publish this evidence so as to enable consulting engineers to draw specifications intelligently without asking for physical impossibilities.

The term "regulation" is vague and has been used very loosely. We understand by the regulation of an alternating current generator, the increase in per cent. of the terminal voltage consequent upon throwing off the load, the speed and exciting current remaining the same. Our problem consists in determining the terminal voltage for any current and power factor for various ampere turns excitation. In practice, it is difficult to make tests under load, especially on very large units. Therefore, it is necessary to have a method which enables us to determine the terminal voltage for any current and power factor from tests which can easily be performed. The first attempt to do this was made by Dr. Behn-Eschenburg of Oerlikon in 1892. It is a curious coincidence that the experiments which Dr. Behn began and which I continued extensively at the Oerlikon Works, were made on types of alternators which bore out and corroborated Dr. Behn's theory, although this theory does not represent the actual conditions on modern machines. The first experiments were made on machines of the Lauffen type, and later experiments were made on machines of the inductor type, both types of machines being carefully designed. Dr. Behn suggested that if the open circuit saturation curve of the generator was

known, as well as the current which the machine generated in short circuit, we could obtain the apparent impedance of the armature by dividing, for a given excitation, the volts on open circuit by the amperes in short circuit for the same excitation. This theory, superficially considered, appears very plausible; but it is evident that it throws together, without explanation or justification, the armature reaction and the self-inductive effects produced by the local fields in the armature.



Regulation Curves on 500 k.w. 3-Phase Induction Generator.

It appears plain that, for all we know, the local fields might be independent of the saturation of the machine, while the effect of armature reaction would, of course, be dependent upon the degree of saturation. The experimental investigation was encumbered by the fact that the power factor plays such an important part in the magnitude of the inductive drop. In order to simplify the conditions, we have only to consider that the drop in an alternator is a maximum if the power factor is a minimum.

It can also be readily shown that if the power factor is diminished below 20 per cent., the drop will practically remain unchanged, the error being extremely small in assuming that a power factor of 20 per cent. or less is equivalent to a power factor zero, as regards inductive drop.

The alternating current generators built during the past ten years have had to operate mainly upon induction motor loads. At least this is true in regard to the generators built in the early nineties in Europe, as induction motors were then used there on a large scale. It seemed to me it was logical to demand that a generator should be capable of standing an induction motor load equal to its rated kilovolt amperes. Therefore, all my machines were designed so that they could give their full rated output in kilovolt amperes on a load of any power factor. These machines were tested by using, as a load, induction motors running idle, so as to be sure that the power factor would be below 20 per cent.

TABLE I.

Amperes Excitation	Actual Terminal Voltage	Calculated Terminal Voltage.		Regulation per cent		
		A	B	Actual.	A	B
10	360	365	356	143.	140	145
20	1110	1115	1140	41.5	41	37.7
30	1700	1688	1840	24.1	25	14.7
40	2100	2073	2290	16.6	18.7	7.4
50	2330	2300	2540	13.7	15.2	4.35
60	2460	2431	2700	12.3	13.1	1.85

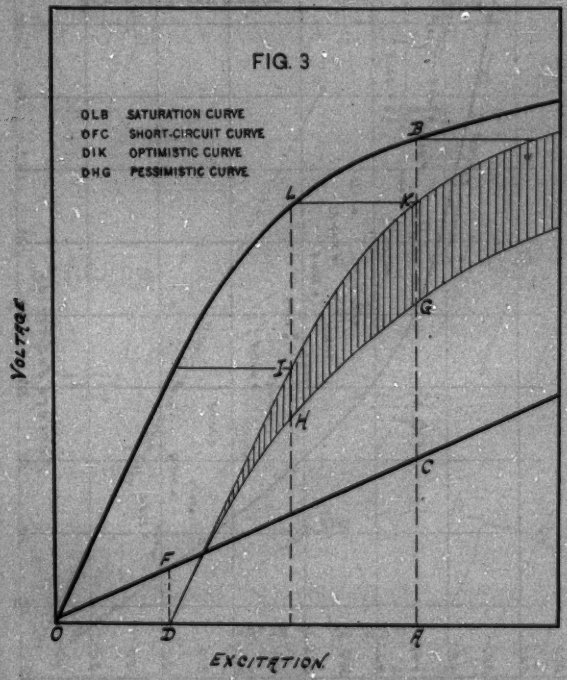
In order to obtain very large currents, I used synchronous motors running without, or with very slight, excitation. The simplification thus obtained in interpreting tests and theory is worthy of notice.

Fig. 1 shows the saturation curves at no load and at 96 amperes load, $\cos \varphi < .2$, as well as the short circuit curve, of a large inductor generator built six years ago at the Oerlikon Works. The magnetic circuit of this machine is represented in Fig. 2.

Applying Dr. Behn's method to these curves and referring to Fig. 3, where O B represents the saturation curve, and O C the short circuit curve, we find the apparent reactance, neglecting ohmic resistance, by dividing A B by A C. If we wish to determine the inductive drop for a current represented by D F equal to one-third A C, we reason, according to Dr. Behn, that as it takes an e.m.f. equal to A B to drive a current equal to A C through the short-circuited armature, it will take an e.m.f. equal

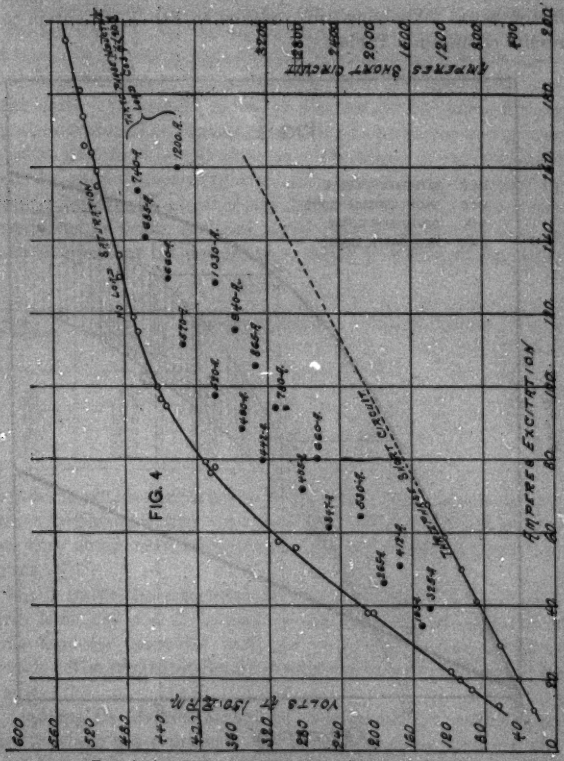
to D F + A C, equal to one-third A B, to drive a current D F through the armature. We thus obtain a point G, B G being equal to one-third A B. Applying the same reasoning to different excitations, we obtain a curve D H G, which represents the terminal voltage at different excitations for a constant current F D at a power factor zero. Applying this method to Fig. 1, we obtain the results compiled in Table I.

FIG. 3



In applying the rule of paragraph 71 of the Committee on Standardization, we have only to remember that, referring to Fig. 3, it takes an excitation corresponding to O D to produce a current D F in the short-circuited armature. Therefore, following the INSTITUTE rule given in paragraph 71, in order to get the load saturation for a current D F on a power factor zero, we have

to deduct the ampere turns O D from the ampere turns on open circuit. The result is curve D I K, the distances between this curve and the curve O L B measured along the abscissa being the same.



Regulation Curves on 500 k.w 3-Phase Generator.

In Table I. there are placed side by side, the actual regulation obtained by experiment and the regulations as calculated from Dr. Behn's method, and as determined by the rule of paragraph 71 The results obtained by the former method are given in column "A"; the results obtained by the latter method are repre-

sented in column "B." It is evident that method "A" gives results which are very nearly accurate, while the error resulting from the use of method "B" is greater than 700 per cent. at high saturations. For the straight part of our saturation curve, the above methods give the same results.

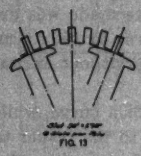


FIG. 13

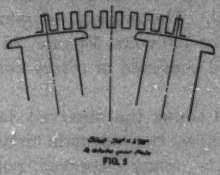


FIG. 3

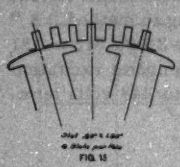


FIG. 15

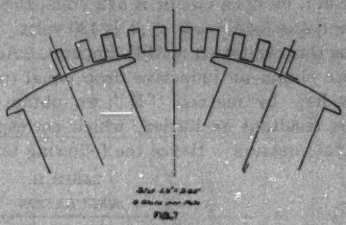


FIG. 7

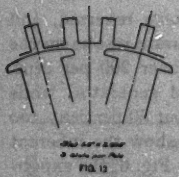


FIG. 12

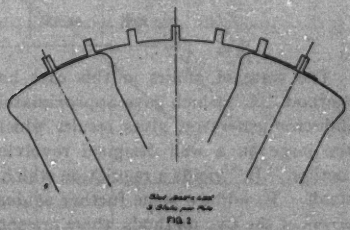


FIG. 2

For the saturated part, method "B" yields in this case a regulation which is several hundred per cent. smaller than the actual regulation, while method "A" yields a regulation which is a few per cent. larger than the actual regulation. These tests were made on a large inductor generator with small air gap and large

pole pitch, which are the best possible conditions for good regulation. Fig. 2 shows the number and size of slots and other details.

We will now apply the two methods " A " and " B " to a 500 k.w., 3-phase generator designed with all the finesses that can be employed to obtain good regulation with greatest economy of material. The machine on which the tests were made was designed for 400 volts, 3-phase, 25 cycles and was run at 150 r.p.m. The load consisted of rotary converters running without excitation.

Fig. 4 shows the observed data in the form of a curve, while Fig. 5 shows the magnetic circuit. Leaving it to the reader to check the many observed points for himself, we will refer to a few points to illustrate the argument. For instance, take the point observed at 160 amperes excitation. Here the e.m.f. on open circuit is 512 volts, the terminal voltage at 1200 amperes load, $\cos\varphi < .2$, is 420 volts. The short circuit current at this excitation is 3400 amperes. According to method " A," we obtain an inductive drop equal to $1200 \div 3400 \times 512 = 181$ volts; by method " B " we obtain 102 amperes excitation as resultant excitation, which corresponds to 448 volts terminal pressure. Hence the following table:

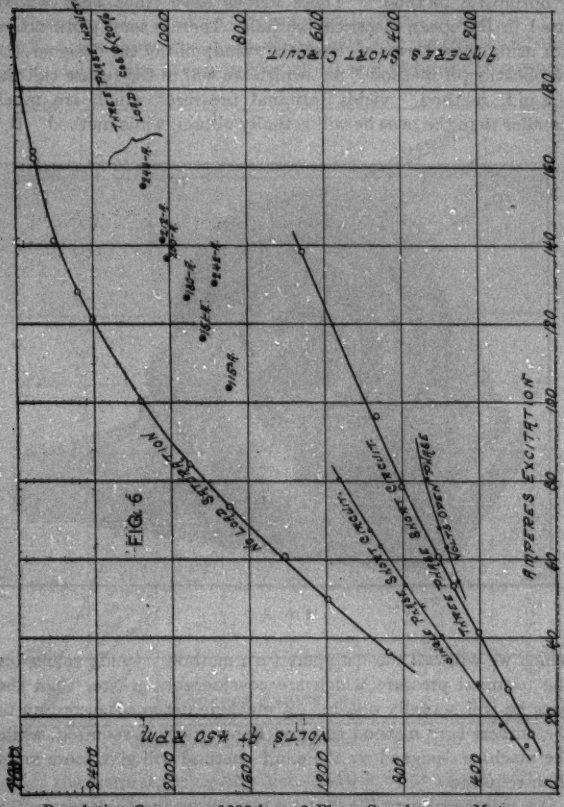
TABLE II.

REGULATION.

Actual.	A	B
22%	54.5%	14.3%

The state of affairs in this case has become reversed, and method " A," which gave approximately accurate results on the inductor generator, gives results which are over 200 per cent. too large on a well designed revolving field generator, while method " B " yields a regulation which is about 50 per cent. too small. To adduce some further evidence to show the inherent errors of the two methods, there are shown in Fig. 6, the experimental curves taken on a 1600 h.p. synchrouous motor operating on a 3-phase system at 30 cycles and 450 r.p.m. The magnetic circuit of the motor is represented in Fig. 7, and a picture of the machine is given in Fig. 8. Method " A " gives, at 155 amperes excitation, 244 amperes load, a terminal voltage of 2130. Method " B " yields a terminal voltage of 2240 volts. The actually

observed terminal pressure was 2130 volts. Now, it is clear that neither method " A " nor method " B " yields accurate results in this case, but method " B " approaches somewhat more closely



Regulation Curves on 1600 h.-p. 3-Phase Synchronous Motor.

to actual facts than method " A " does. These curves were taken by running the synchronous motor as a generator. The tests were made by taking two machines, one running as generator, the other as motor.

Returning once more to Fig. 3: Some five years ago the writer named the method "A," which yielded the regulation curve D H G, the "pessimistic method," while he called the curve D I K obtained by applying method "B," or the INSTITUTE method, the "optimistic method." These names have since been widely used in European electrical journals. There is some justification for using these terms as, from the standpoint of the designer, the application of method "A," which we will in the future call the "e.m.f. method," yields terminal pressures which are much smaller than the ones he will actually obtain, while method "B,"

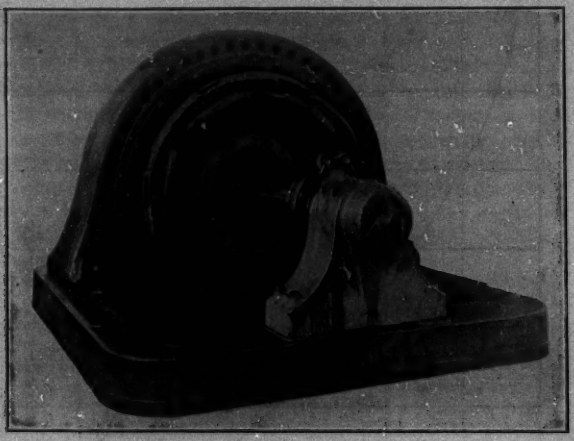


FIG. 8.

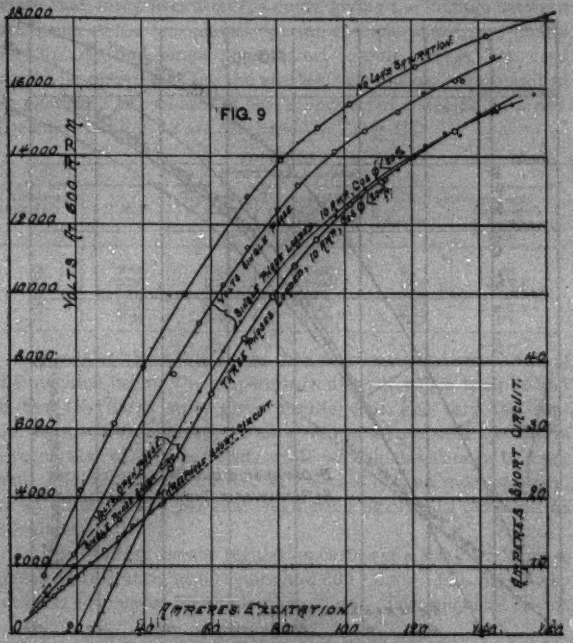
which we will call the "ampere turn method," yields values for the terminal pressure which are considerably greater than the ones he will actually obtain. A machine designed according to the ampere turn method will give less volts than required, while the machine designed by the e.m.f. method will give more volts than required.

Again referring to Fig. 3, it is clear from the evidence so far adduced that the curve for the actual terminal voltage lies between the two curves D I K and D H G; that is, between the optimistic and pessimistic curves. But, further to corroborate this statement, there are shown regulation curves in Fig. 9, Fig.

10 and Fig. 11, Figs. 10 and 11 being reproductions of the 3-phase and single-phase load curves with the optimistic and pessimistic curves plotted in the diagrams. Fig. 9 shows also the e.m.f. between the open phase and either of the two terminals of the loaded phase. This curve will be referred to later.

The magnetic circuit of this machine is shown in Fig. 12.

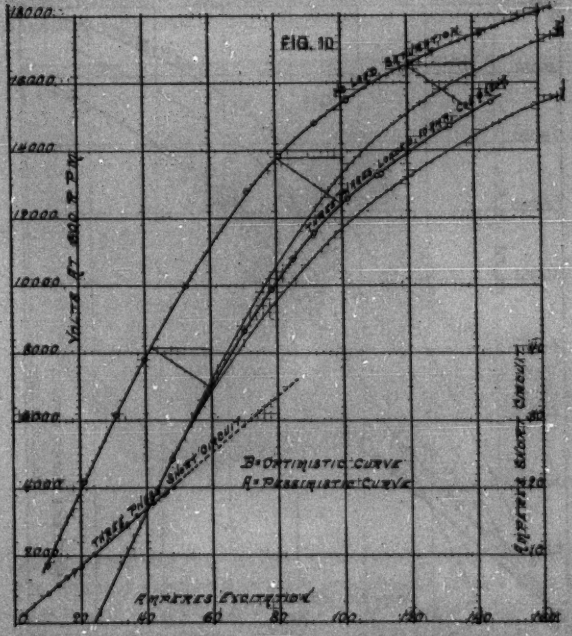
The figure shows the shape of the poles and the shape and size of the slots. The curves in Figs. 9, 10, and 11 belong to a gener-



Regulation Curves on 3-Phase Generator.

ator the normal rating of which is 200 k.w. at 13,000 volts and 60 cycles. The load saturation was taken by running two of these machines together, one operating as generator, the other as synchronous motor. The power factor varied between 8 and 15 per cent. Fig. 10 represents a 3-phase load, while Fig. 11 represents a single-phase load. These curves are well fitted to bear out the essential parts of the theory of the regulation of alter-

nators, as they indicate clearly that the armature ampere turns which are opposed to the field ampere turns are large in the 3-phase machine and small in the single-phase machine; while the e.m.f. produced by local armature fields is small in the 3-phase machine and large in the single-phase machine. These conditions result in the load saturation curve of the single-phase machine lying very close to the pessimistic curve, while the load saturation of the 3-phase machine lies about half way between the



optimistic and pessimistic curves. These diagrams show the armature reaction separated from the self-inductive effect of the local armature fields. The side of the triangle which is parallel to the abscissa represents the armature reaction, and the side parallel to the ordinate represents the self-inductive effect of the local fields. From the curves in Figs. 10 and 11 it is seen that by resolving the total inductive drop into such components

results are obtained which are very closely in agreement with actual observation. However, there remains the difficulty of separating these two components. We add Fig. 12 to our experimental data, representing the regulation curves of a 100 k.w., 900 r.p.m., 60 cycle, 3-phase generator, the magnetic circuit of which is represented in Fig. 13. The curves contain a no load saturation; a saturation curve for 30 amperes 3-phase load of low power factor; a saturation curve for 30 amperes, single-phase load, low power factor; a curve giving the voltage between either one of the two phases operating single-phase, and finally the 3-phase and single-phase short circuit curves. It need hardly be remarked that the single-phase curves were obtained by operating two phases of the Y connected machine in series. The curves in Fig. 12 are condensed in Table III.

TABLE III
100 *K.W., 3-Phase Generator.*

Amperes Excitation	E. M. F.	Terminal Voltage.	Terminal Voltage Calculated by Institute Rule.	Regulation per cent.	
				Observed.	Calculated by Institute Rule.
16	2080	1050	1050	98	98
20	2330	1530	1600	52.5	45.6
24	2500	1850	1950	35.1	28.2
28	2640	2060	2260	28.2	16.8
32	2755	2250	2460	22.5	12

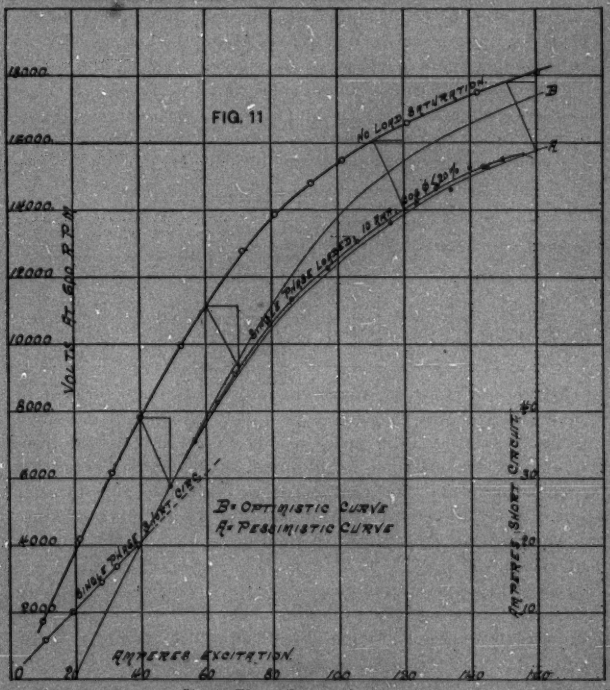
A glance at this table shows that as soon as the saturation of the machine begins, the ampere-turn method, which is embodied in the INSTITUTE rule, gives results that fall very far from the mark. For instance, we observed at 28 amperes excitation a regulation of 28.2 per cent., while we calculated only 16.8 per cent. At 32 amperes excitation the case is even more striking, as we observed 22½ per cent. regulation against 12 per cent. as calculated.

In Fig. 14 are given the regulation curves of a 350 k.w., 2-phase generator operating at 60 cycles and 600 r.p.m. This figure also contains the curves for single-phase load. The magnetic circuit

TABLE IV.
350 *K. W., 2-Phase Generator.*

Amperes Excitation.	E. M. F.	Terminal Voltage.	Terminal Voltage Calculated by Institute Rule.	Regulation per cent.	
				Observed.	Calculated by Institute Rule.
20	1700	640	640	166	166
30	2250	1440	1530	56.2	48
40	2550	2030	2160	25.6	18
50	2775	2360	2500	17.6	11
60	2980	2600	2740	13.8	8.1
70	3140	2740	2920	14.6	7.55

of this machine is shown in Fig. 15. I want again to call attention to the fact that if these curves are checked by the two methods mentioned in this paper, we find that for 2-phase and 3-phase machines, the curve of the terminal voltage lies between the two curves termed the optimistic and pessimistic curves, while the single-phase load curves approach very closely to the pessimistic curve.



Single-Phase Regulation Curve.

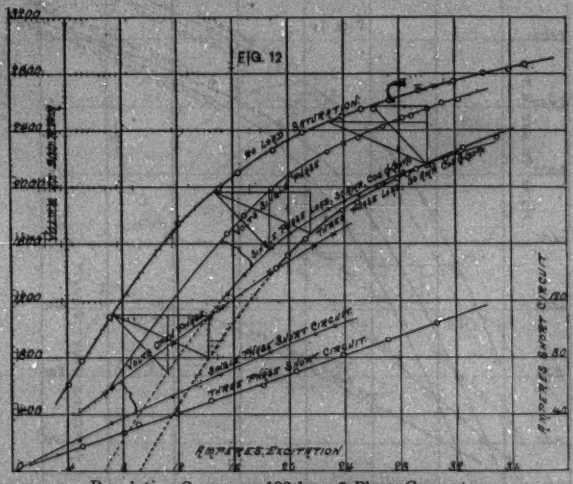
The data of Fig. 14 are represented in Table IV. which, after what has been said, requires little comment.

This table shows conclusively that on most modern machines the INSTITUTE rule gives results which do not at all correspond to actual observation.

It has been demonstrated by the large number of tests de-

scribed in this paper that the " ampere turn " method does not give satisfactory results in determining the regulation of an alternating current machine. The method is inherently wrong, as it neglects the extremely important inductive effect of local fields in the armature. It has also been shown that the e.m.f. method gives entirely misleading results. Therefore, it is proved conclusively that it is not possible to obtain the regulation of an alternating current machine by using no other characteristic than the saturation and short circuit curves.

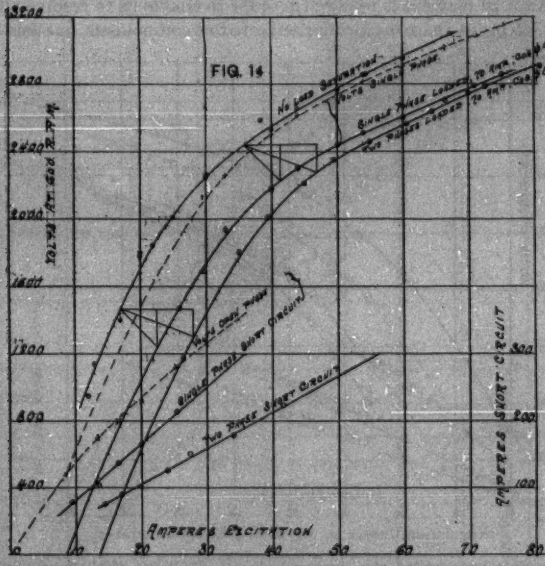
Another element is required in order to enable us to resolve all the effects of the armature current into two components, one com-



Regulation Curves on 100 k.w. 3-Phase Generator.

ponent representing the demagnetizing effect of the armature, and the other component representing the inductive drop produced by local armature fields. Any theory which aims at a complete explanation of the phenomena produced by a load in the armature of alternating current machines must conform to actual observation and fact. Therefore, the two methods which have been criticised in this paper stand condemned. They should not be used for the quantitative determination of the regulation, because they do not explain nor express the facts. We must frankly admit the existing predicament that there is no simple

method which explains all the facts observed, although the designer undoubtedly creates for himself an empirical method by which he can, within very close limits, determine the actual regulation without every time actually performing the experiment. It is entirely a matter of skillful designing to reduce the inductive drop in a machine. It is plain that it is necessary to avoid any leakage from pole to pole and for that reason it is essential to use large pole pitches; in other words, to place the poles far apart from one another. This matter of field leakage is



well brought out by a comparison of the regulation curves of the inductor generator in Fig. 1 with the regulation curves represented in the other figures. The poor regulation of the inductor generator is due to the field leakage between two inductor horns producing a counter e.m.f. Speaking from a large experience in the designing and testing of this type, I venture to assert that it is impossible to make these machines so that the load regulation curve lies very much above the pessimistic curve. While it is perfectly possible to build inductor generators with good regula-

tion, this can be done only at the expense of a great deal of material, which fact condemns this type not only from a commercial standpoint, but especially from the point of view of the scientific engineer, whose aim it must be to design machines of excellent properties with the least expenditure of material.

In looking at Figs. 10, 11, 12 and 14, in which the drop in the armature has been resolved into its two components, it is seen at a glance that if we want to take advantage of the high saturation it is essential to reduce to a minimum the local fields in the armature, as this reduces the side of our triangle parallel to the

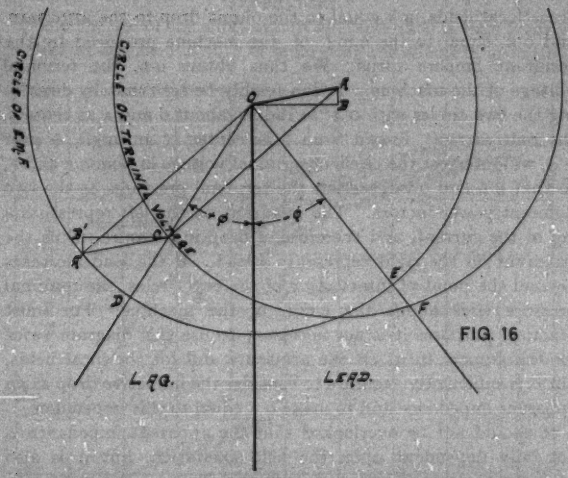


FIG. 16

Kapp's Diagram for the Determination of the Regulation at Different Power Factors.

ordinate. As a matter of design, this can be accomplished by using a large pole pitch, a narrow armature, and, to some extent, a large number of slots per pole and per phase. The large pole pitch which thus proves so useful has the further advantage of improving the ventilation of the machine, thus leading to cool operation. A large pole pitch makes a machine easily accessible, and increases the radiating surfaces, as the most effective part of the radiating surface of the machine lies in the armature faces.

If, for a given excitation, we have determined the drop of a machine for a given current and zero power factor, we can determine the regulation for any power factor for the same current, by using the vector diagram. The most elegant method is that represented in Fig. 16, originated by Mr. G. Kapp. After resolving the inductive drop into its two components, the armature reaction and the local fields, we can compose the ampere turns on the fields, O A′, with the ampere turns on the armature, O A, finding the resultant ampere turns O C. Next, applying the same process to the local fields, we can draw another diagram, making O B equal to the e.m.f. produced by these local fields, B A equal to the ohmic drop in the armature, and O A, equal to the e.m.f. of the machine produced by the resultant ampere turns. We thus obtain O C, the terminal voltage of the machine. It can readily be seen that, by describing the two circles with O A′ as radius, about O and A as centers, the *radii-vectores* drawn from O as center at an angle $+\varphi$ or $-\varphi$, will intersect the circle of terminal voltage in points C and F, so that O C and O F represent the terminal pressures at the two different power factors. The quadrant on the left represents a lag of the current, and therefore, a drop in pressure, while the quadrant on the right represents a lead. If the lead increases beyond the point of intersection of the two circles, the terminal pressure rises above the e.m.f. of the machine. For most practical purposes it is not necessary to use this diagram twice for the ampere turns on the armature and for the local fields, but it is sufficiently accurate to consider the inductive drop as an apparent impedance and to make O A equal to this impedance.

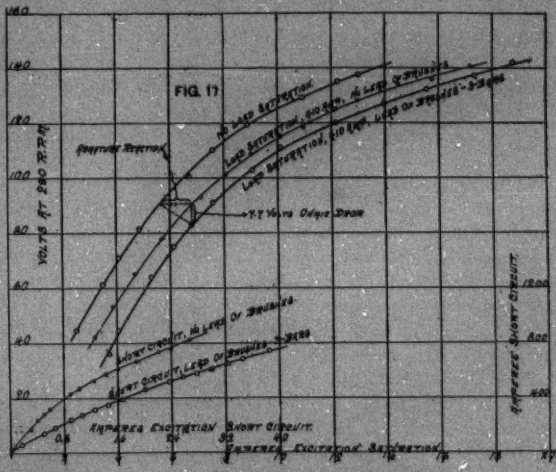
It should not be overlooked that the apparent impedance is not only dependent upon the field excitation, but it is also dependent upon the armature current. This can easily be seen by working out a few values for the apparent impedance in Fig. 4. It will thus be found that the impedance, while a constant at low saturation, increases rapidly with the increase of the armature current at the same field excitation.

It is interesting to study the curves giving the pressure on the open phase while taking out single-phase current, as this has important bearing on the question of regulation of 2-phase and 3-phase machines when operating on a lighting load. It can be seen from Figs. 9 and 12, which represent 3-phase machines, 2 phases in series loaded, the third phase open, that for high saturation the curve for the pressure on the open phase between

the terminal of the open phase and either of the terminals of the loaded phases lies considerably higher than the curve for the pressure on the loaded phases. The same is true to almost the same extent of the 2-phase machine, the curves of which are represented in Fig. 14. This shows conclusively that there is little preference in favor of either type of machine as far as regulation is concerned.

General Remarks Regarding the Value of the Short Circuit Characteristic in the Design of Electric Generators.

While the use of the short circuit characteristic is thus greatly invalidated by the difficulty of separating the effects of armature



reaction and of the local fields, it yet remains a valuable characteristic of the machine. It has been shown conclusively in this paper that we cannot use the saturation and short circuit curves alone to determine the regulation of a machine; but it has been indicated that, by plotting from these two curves, two other curves which I termed the " optimistic " and " pessimistic" regulation curves, it is possible, with a certain degree of accuracy, to plot the actual regulation curve between these two last named curves. In doing this, there is, of course, much left to the discretion and judgment of the designer, who, nevertheless,

derives a great deal of help from these curves. The work of designing is more a work of art than a work of science. It is true that sound, scientific knowledge is absolutely required, but scientific knowledge without engineering intuition avails very little and leads merely to abortive designs. The great designers in electrical engineering have not always clearly understood why they have designed a machine in a certain way. They have been guided less by science than by intuition.

The short circuit characteristic can be very usefully applied to the regulation of direct current generators, thus supplying a means of finding the ampere turns necessary to compound or over compound a machine. Although somewhat foreign to our subject, there are shown in Fig. 17 the saturation, short circuit and regulation curves of a 75 k.w. direct current generator. There are plotted in this figure the saturation curve at no load, the load saturation at 410 amperes with no lead of brushes, and the load saturation at 410 amperes with a lead of brushes equal to three bars. There are also plotted two short circuit curves, one with no lead of brushes, and the other with a lead of three bars. These short circuit curves have been obtained by separately exciting the generator and short circuiting the armature. The difference between the ampere turns required with lead and without lead of brushes at 410 amperes in the armature corresponds to the armature reaction of the machine. It will be found that with no lead of brushes, the distance between the no load and load saturations measured along the ordinate are the same for any saturation, while we can easily determine the load saturation with a lead of three bars, by combining the armature reaction and the ohmic drop in the armature as shown in Fig. 17. The short circuit test on direct current machines has the further advantage that it is a rather severe test for commutation, requiring very little power for driving. This method has been used by the writer for testing very large direct current machines which could not be operated in the testing room under full load. A machine which commutates satisfactorily in short circuit will surely commutate satisfactorily at full load.

Summary.

To sum up the results of this paper: It has been demonstrated that the application of the ampere turn method, as proposed by the Institute rules, leads to entirely wrong results. It makes machines of inferior design and large leakage appear in regulation

not only equal to, but even better than, machines of careful and superior design. In a word, the method is not scientific and not in accordance with fact and observation.

The ampere turn method, while very simple is inherently wrong, and it should, therefore, not be used, even it if is impossible to substitute an equally simple rule for it. The desire to have such a simple rule should not tempt us to adopt one that is false. There is a tendency among engineers to neglect the element of uncertainty which is so prominent in all engineering questions.

In conclusion, I wish to thank Mr. T. S. Allen, one of my assistants, for the pains he has taken in plotting the curves presented in this paper.

A paper read at the 177th meeting of the American Institute of Electrical Engineers, New York, May 19, 1903

A STUDY OF THE HEYLAND MACHINE AS MOTOR AND GENERATOR.

BY COMFORT A. ADAMS.

The Heyland motor consists essentially of an induction motor with short-circuited secondary, and a commutator by means of which exciting current may be supplied either to the short-circuited winding or to a separate exciting winding. With either form, the power-factor can be controlled by means of the current sent in through the brushes.

Introduction.

The experimental work which forms the basis of this paper was carried on during the early part of last summer in connection with an experimental machine built by the General Electric Co., and kindly loaned to the writer. The work was first undertaken by two of the senior students in Electrical Engineering as a thesis, but owing to the shortness of the time at their disposal, very little was accomplished. The writer, having become interested, then undertook the work on his own account.

The machine tested was not of the exact type advocated by Mr. Heyland, and consequently the results will not have the same directly practical value. The work was however intensely interesting to the writer, and if his interest in the interpretation of minor phenomena has carried him beyond those having practical value, he asks pardon and can only hope that the results here recorded may be of some value to those working along similar lines.

Before proceeding to the discussion of the particular machine under consideration, it may not be out of place to review briefly the history and general theory of the subject.

If any stationary closed coil direct-current armature such as a Gramme-Ring armature, be supplied with p symmetrical poly-

phase currents through p brushes symmetrically placed around its commutator, there will be produced a magnetic field which revolves around the periphery of the armature with an electrical angular velocity equal to $2\pi n$, n being the frequency of the impressed e.m.f. If now the armature be revolved while the brushes remain stationary, the space velocity of the revolving field will remain the same, since the points at which the currents enter the armature are stationary. We have an exactly analagous case in every direct-current armature supplied with a continuous current through stationary brushes, the m.m.f. of this current remaining stationary in space, no matter at what speed the armature may revolve.

As the space direction of the armature reaction in this latter case depends upon the position of the brushes, so does the space-phase of the revolving field in the alternating current case. The usefulness of this arrangement, however, depends upon the fact that when running at synchronism, the total reactance of the winding drops to a very small quantity, provided that p, the number of phases is relatively large, and, under the same conditions, the sparking at the brushes is very light.

By this means it is possible to supply the exciting current of a polyphase motor or generator by means of the polyphase currents delivered to or by the machine in question, without sacrifice of power factor; in fact, when applied to an induction motor, the current taken may be made by over-excitation to lead the impressed e.m.f.

The principle described above was first employed by Görges[1] in 1891, in a polyphase series motor, the stationary part of which was fitted with the ordinary polyphase windings, such as used on an alternator armature, or on the stator of an induction motor, and the rotating part of which consisted of a direct current armature with commutator and brushes, as above described, the two windings being connected in series; see Fig. 1.

This was merely the application of the revolving field idea to the old single-phase series motor, its chief advantage over the latter being the high power-factor and the reduction of the sparking at synchronism.

At other speeds, however, the sparking is serious, due to the currents induced in the short circuited coil by the slip e.m.f., and

1. *Elektrotechnische Zeitschrift*, Dec. 25, 1891. The revolving brush motor of Le Blanc (Comptes Rendu, July 29, 1889), involves the same general principle, but applied in a different way, the object being to make the motor self starting rather than to improve the power factor.

as the series motor is not a constant speed motor, Görges' machine found no commercial field of usefulness. In other respects than those mentioned, the behavior of this machine is exactly similar to that of the single-phase series motor.

The advent of the induction motor turned the attention of investigators from the commutator motor, and five years elapsed before Blondel[1] described a very interesting though complicated combination of the commutator and induction motors.

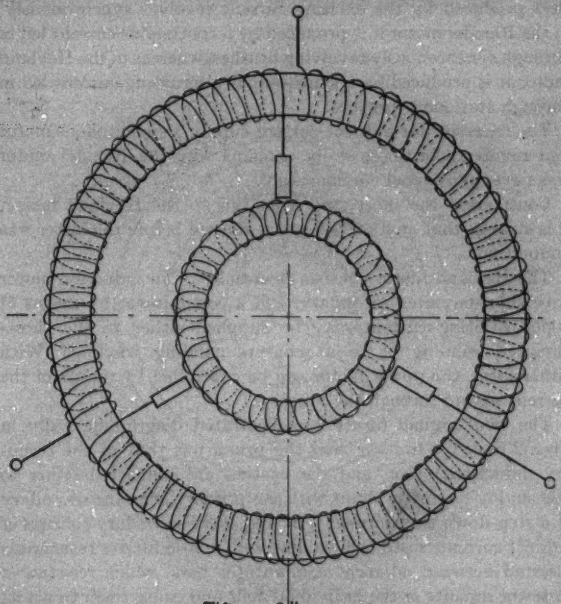


FIG. 1. GÖRGES MOTOR.

It consisted of an ordinary induction motor with short circuited secondary and an additional closed coil direct current rotor winding with commutator. This latter winding was supplied with continuous current through a pair of brushes revolved at primary frequency by means of a synchronous motor.

This motor is said to have operated perfectly without sparking, and with a power factor entirely within control by means of the

NOTE 1. (*L'Eclairage Electrique*, Aug. 29, 1896).

continuous exciting current. Theoretically, there is every reason to believe that it should so operate, owing to the long commutation cycle. In other respects than that of commutation the Blondel motor is exactly similar to one of the forms suggested by Heyland, in fact to that form the tests of which are recorded in the following pages, and so far as the compensation for wattless current is concerned, the theory given below of the Heyland motor applies strictly to Blondel's motor. In both motors the field produced by the exciting current revolves synchronously; in the Blondel motor it is produced by a continuous current led in through synchronously revolving brushes, whereas in the Heyland motor it is produced by a synchronous alternating current led in through stationary brushes.

The necessity for a direct-current supply, a synchronous motor and revolving brushes, easily explains why the Blondel motor was never considered commercially.

Considering the short step from this to the Heyland motor, it is strange that another five years elapsed before the latter was announced.[1]

The Heyland motor consists essentially of an induction motor with short-circuited secondary, and a commutator by means of which exciting current may be supplied either to the short-circuited winding or to a separate exciting winding. With either form, the power factor can be controlled by means of the current sent in through the brushes.

The two original forms[2] are illustrated diagrammatically in Figs. 2 and 3. In both cases the primary is that of the ordinary induction motor, and the brushes are connected either to the supply circuit in shunt with the primary or to the secondary of a step-down transformer. In Fig. 2 the secondary consists of a direct current closed coil winding with non-inductive resistances inserted between adjacent commutator bars, which resistances close the circuits of the individual coils and cause them to act as the short circuited secondary of the ordinary induction motor.

Another important function of these resistances is to receive the commutation kick of each coil as it passes a brush, and thus to minimize the sparking tendency.

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1. *Elektrotechnische Zeitschrift*, Aug. 8, 1901.

2. Mr. Heyland is still experimenting with numerous varieties of windings, some of which have been recently described, see *E. T. Z.*, 1903, Jan. 22d, Jan. 29th, Feb. 5th, March 19th. These differ, however, so materially from the type tested that they will not be here considered.

But these resistances have still a third function, namely that of distributing the exciting current in the several coils of the rotor in such a way as to avoid the harmonics of the three belt winding.

Fig. 3 shows the second type, which was that tested by the writer. The short-circuited secondary is in this case a squirrel cage shown in the tops of the rotor slots, and the separately excited winding is shown in the bottoms of the rotor slots. The rotor windings are exactly similar to those of the Blondel motor. This

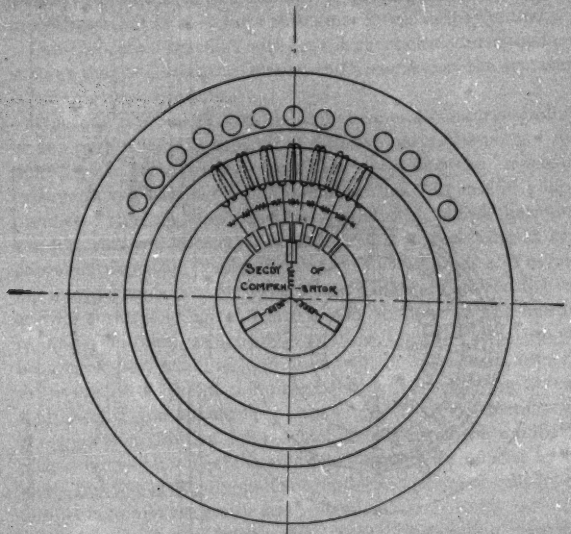


FIG. 2

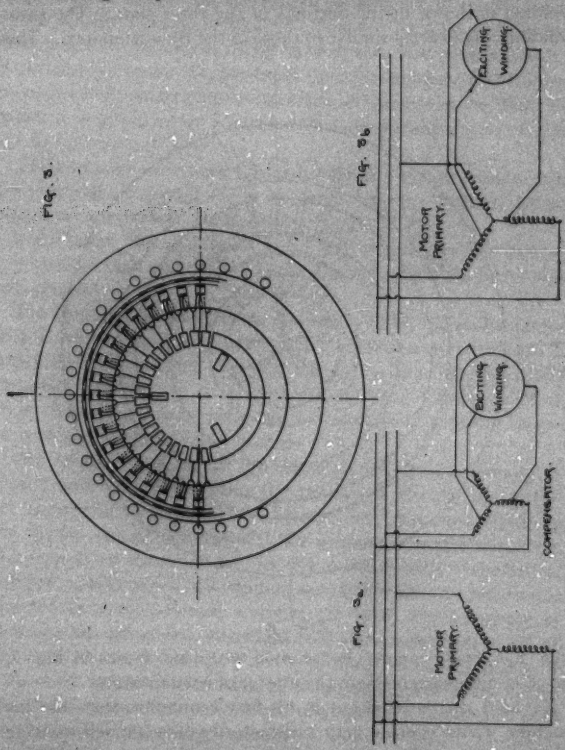
type has many points in common with that shown in Fig. 2, the chief difference being in the matter of commutation.

Heyland also pointed out in his first communication that his machine would operate very satisfactorily as a self self-exciting alternator.

Shortly after the announcement of the Heyland motor, M. Latour[1] described a machine just like that of Fig. 3 without the squirrel cage, but intended primarily as generator. The only

1. *L'Industrie Electrique*. 1902. Feb. 25th, April 10th, April 25th.

difference between this and the Görges machine is that, in the former, the armature is connected in shunt, and in the latter case in series with the field. Although there is no path especially provided for the slip current in the Latour machine, the armature current is closed through the supply circuit, and slip currents do flow along this path as will be shown below.



More recently Osnos[1] has described a machine in which the alternating exciting current is first commutated by means of a small auxiliary direct current armature on the shaft of the main machine, and then led into the rotor exciting winding by means of slip rings.

1. (*E. T. Z.*, Oct. 16, 1902.)

Reactance of Exciting Winding.

In the calculation of any such machine it is necessary to know what is the effective reactance of the exciting winding. This problem, and the one of commutation in the same class of machines, are closely allied, and have been much analyzed by various writers.[1] The solutions obtained have differed very widely. Accurately analyzed for an actual machine, the problem is a serious one, but it is not difficult to get a general view of the more important factors and the manner in which they enter.

Consider first a machine without the short circuited secondary, such as that of Latour or Görges, and assume that the armature is running at synchronism.

The total flux linked with the armature or secondary winding, or any part of it, may be divided into two parts, the *mutual flux* linked with both primary and secondary and the *secondary leakage flux*. Consider first the mutual flux; in case of a large number of phases supplied with symmetrical, simple harmonic e.m.f.'s, this will consist of a sinusoidal field revolving at synchronous velocity. Therefore, since the armature is also revolving in synchronism, there is no relative motion between the two and no corresponding reactance e.m.f. If however the number of phases be small, as is usual, say three, then the armature will be a three-belt winding, and there will be introduced into the revolving field several prominent harmonics revolving at submultiples of the synchronous velocity. These harmonics will give rise to a reactive e.m.f. which decreases as the number of phases increases. There is another harmonic introduced by the teeth, but this is usually made negligible in any set of coils by the vernier action of the stator and rotor slots.

Consider now the *leakage flux:* the corresponding reactance is evidently determined by the frequency of the current in the circuit in question; but although the average current in any individual coil is of slip frequency, the circuit in question is that between two adjacent brushes, the current in which is of primary frequency.

The current variation in the coil undergoing commutation does not affect the reactance, since the commutation is forced and

1. Le Blanc, *L'Eclairage Electrique*, Oct. 26, 1901.
Latour, *L'Eclairage Electrique*, Nov. 23, 1901.
Heyland, *L'Eclairage Electrique*, Nov. 30, 1901.
Poincare, *L'Eclairage Electrique*, Jan. 18, 1902.
Latour, *Electrical World and Engineer*, Feb. 1, 1902. Many of the references given elsewhere in this paper include discussions of these points.

represents a slight increase in the energy component of the e.m.f. rather than in the reactive component. The leakage reactance is thus determined by the primary frequency.

Commutation.—The conditions for ideal commutation are, as in the case of a direct current machine, that the flux linked with a coil should remain constant during its commutation period, and that the brush-contact resistance should be high relatively to that of the coil.

The second condition is as easily fulfilled in the alternating as in the direct current machine, but not so with the first. At synchronism there is no relative motion between the fundamental field and the coil in commutation, but there is a considerable relative motion between this coil and the harmonic fields, which, in the case of a three-phase armature, is the cause of heavy currents in the short circuited coil and sparking at the brushes.

The tooth harmonics may also be of considerable magnitude in the case of a short air gap and open slots, see Fig. 4*g*, described below. The resistance to commutation offered by the leakage reactance is the same as in a similar direct current machine, but here it is not possible to neutralize this effect by shifting the brushes. This is however of little importance as compared with the first mentioned harmonics. The ordinary devices for the suppression of sparking will be helpful here, but not so effective, owing to the greater e.m.f.'s in the short-circuited coil.

The above applies primarily to a secondary consisting simply of a closed-coil direct-current armature. In Heyland's motor, Fig. 2, the non-inductive resistances between bars serve as a means of distributing the exciting current so as to eliminate the harmonics otherwise due to the wide phase belts, even in the case of single-phase excitation. These resistances also receive the commutation kick due to the leakage reactance.

The squirrel cage in Fig. 3 serves the same purpose, but not so perfectly. Here the field harmonics are largely eliminated by the damping effect of the low resistance squirrel cage, or, the m.m.f. harmonics due to the nature of the exciting winding are balanced by secondary currents in the short-circuited rotor winding. This in fact is the explanation of the action of the machine shown in Fig. 2, the induced currents and the exciting current combining in the same winding to produce a sinusoidal m.m.f. distribution, whereas in the machine of Fig. 3 they are in separate windings. The less satisfactory commutation in the

latter case is due partly at least to the leakage between the two secondary windings.

The remarks above concerning reactance and commutation apply only to synchronous operation. Whenever there is slip, there will be a slip e.m.f. and current in the short-circuited coil, which, in the case of the simple closed-coil winding, or in the machine of Fig. 3, will tend to cause sparking. In the machine of Fig. 2, most of the slip current will be shunted across the commutator bar-connections with which the brush is in parallel. But if the slip is large, sparking will occur even here. There will also be a slip current in the main part of the exciting winding, which in the two first mentioned machines will flow through the brushes into the supply circuit. In the machine of Fig. 2, a large part of this slip current will be shunted through the non-inductive bar-connections.

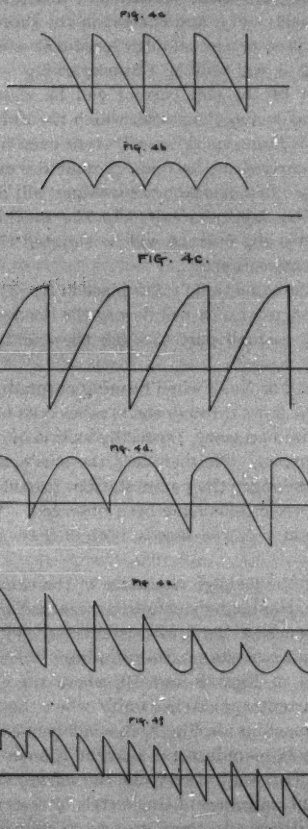
Practically the same thing takes place in No. 3, for with a given *total* slip current, most of it will flow in the low-resistance squirrel cage, and only a small part through the exciting winding and brushes.

In either No. 2 or No. 3 when running normally, the amount of slip current that flows through the brushes does not add seriously to that otherwise necessary, especially as it is in quadrature with the exciting current. Neither does the slip e.m.f. in the short circuited coil endanger the commutation, provided the ordinary commutation precautions have been observed. But when starting, or running at very low speeds, both of these disturbances are considerable.

The effect of the leakage reactance of the exciting winding of either of these Heyland machines is practically negligible. In No. 3 the presence of the low-resistance secondary reduces the apparent reactance of the exciting winding; this is shown for the machine tested in Figs. 18 and 19, where the power factor of the exciting current approaches unity when the slip approaches zero. In the machine of Fig. 2, the independence of the individual coils tends to reduce the current therein to the slip frequency. This is readily seen from the curves of Fig. 4, which show the current variation in single coils of the exciting winding of a machine without any commutator bar connections. Curves (*a*), (*b*) and (*c*) are for three different coils of a three-phase machine at synchronism and (*d*), (*e*) and (*f*) for single, three and six phase machines respectively, each with a considerable slip.

Fig. 4*g* is an oscillograph curve of the potential difference

between two adjacent commutator bars of the machine tested, while running under full load. The long wave, only a small fraction of which is shown, is of slip frequency and shows the



average current; the large kinks are due to the commutation or the shifting of the coil in question from one phase to the next; and the small kinks are due to the teeth. But for the tooth

harmonic, this curve would look very much like that of Fig. 4*e*. Each of the curves *d*, *e* and *f*, may be considered as approximately made up of a long slip wave, and a very prominent harmonic of about p times the primary frequency, where p is the number of phases. If however the coil in question is more or less independent, as in the machine of Fig. 2, these harmonics will be largely damped out, leaving only the main exciting current of slip frequency. This is what was referred to on page 764 as the distributing function of the commutator-bar connections and is also a statement from a different point of view, of what was said at the bottom of page 768 regarding sinusoidal m.m.f. distribution.

Description of Machine Tested.

As the analysis given below relates primarily to the type of machine tested, it will be well to get that machine clearly before us. It was a ten h.p., three-phase, 440-volt, 60-cycle, 6-pole

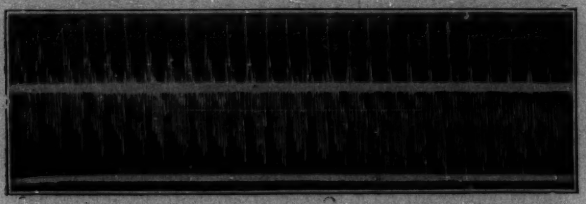


Fig. 4g

induction-motor (see Fig. 5), with a low-resistance squirrel cage in the bottom of the rotor slots, and a separate exciting winding in the tops of the rotor slots.

The exciting winding was of the ordinary two-path or series variety, connected to a 107-bar commutator, and as there were 54 rotor slots, one-half slot was empty. But the real number of bars was only 35, or about 6 per pole, since the commutator leads were disconnected from two of every three bars, and the three bars soldered together. There were thus 33 sets of three coils each and two sets of four coils each.

The brushes were of copper gauze, two sets of three each, each set being provided with an independent rocker. After some preliminary tests, these rockers were graduated in electrical degrees with arbitrary zeros.

The remaining dimensions are given in Fig. 5, except the

length of core parallel to the shaft, which is five inches between heads. The primary is star-connected, and has a hot resistance, $r_1 = .75$ ohms per phase, and a leakage reactance $x_1 = 1.$ ohm per phase.

The squirrel cage has an equivalent hot resistance of $r_2 = .43$ ohms per phase (reduced to primary turns), and an equivalent

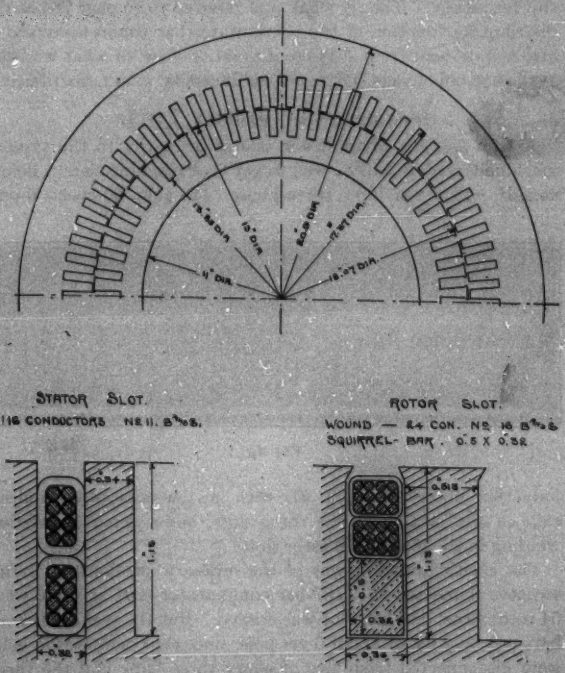


FIG. 5

leakage reactance with respect to the primary of $x_2 = 1.88$ ohms. $x_1 + x_2$ was measured at standstill and the two separated by calculation. X_1 is larger because the squirrel cage was concentrated in the bottoms of the slots, and because of the over hanging rotor teeth.

The extra exciting winding, when supplied with 3-phase excitation through 3 brushes at intervals of 120 electrical degrees, is delta-connected and a three-belt winding, whereas the primary is a six-belt winding; *i.e.*, in the ordinary 3-phase winding there are six phase-belts per pair of poles, the currents in any two adjacent belts differing in phase by 60°, whereas in the closed-coil direct-current winding, there are only three phase belts, the currents in which differ by 120°. This is an important distinction since both in the generation of e.m.f. and of m.m.f. by a three-belt winding, there is a considerable loss of effectiveness due to the breadth of each belt, and the consequent differential action going on between different parts of the same belt. The differential factor for a distributed six-belt winding in a sinusoidal field is $\frac{6}{2\pi} = .955$, that for a three-belt winding is $\frac{3\sqrt{3}}{2\pi} = .827$, and the differential factor of the latter with respect to the former is $\frac{\sqrt{3}}{2} = 866$.

The actual hot resistance per delta phase of this winding was 2.7 ohms, or reduced to star, .9 ohms.

The equivalent resistance per star phase reduced to primary turns and to a six belt basis is, $r_s = 2.7 \left(\frac{72\times16}{53.5\times24}\right)^2 \left(\frac{2}{\sqrt{3}}\right)^2 = 2.9$ ohms. This is the resistance to be used in the calculation of the slip current in the exciting winding. The differential factor enters twice, since it affects both the slip e.m.f. induced in this winding, and the m.m.f. value of the resulting current as compared with the same current in the primary. This assumes a sinusoidal flux distribution, and neglects the resistance of the outside circuit through which the slip current must flow; it is therefore only approximate.

The equivalent leakage reactance of this winding reduced to primary turns is, $x_s = .86$.

Its mutual leakage reactance with respect to the squirrel cage is only a little less than this.

As there will be slip current in both the squirrel-cage and the exciting winding, it will be convenient at times to treat them as a single winding in which case their equivalent hot resistance and leakage reactance[1] will be respectively (for slips within the working range) $r = .375$ and $x = 1.25$ ohms.

1. All the reactances are given reduced to primary frequency.

A rather interesting fact which has, however, no particular bearing on the subject of this paper, is that for low speeds, *e.g.*, at standstill, the equivalent resistance is considerably larger, and the reactance smaller, than that given above. If the copper were uniformly distributed throughout the slot section, this would not be the case.

Theory of Operation.

As in the induction motor, the magnitude and speed of the revolving field are, for any given machine, practically dependent upon the magnitude and frequency of the impressed e.m.f. In the particular machine under consideration, there are three windings and three distinct currents, the resultant m.m.f. of which must be just sufficient to produce the above-mentioned flux under all conditions, remembering of course that as the primary drop increases with the current, the counter e.m.f. and flux will decrease slightly.

The only difference between this and the ordinary induction motor problem is that here we have an additional externally supplied current and m.m.f. to take account of, one that revolves with synchronous velocity, if supplied from the same source as that of the motor current, but one whose space-phase with respect to that of the primary e.m.f. depends not only upon its time-phase but also upon the position of the brushes. It is possible, therefore, by means of the brushes, to give to the m.m.f. of this exciting current any desired space-phase with respect to the other m.m.fs. These relations will be more readily appreciated with the aid of a vector diagram.

The familiar induction-motor diagram is shown in Fig. 11. All secondary constants are reduced to primary turns. Φ is the flux common to both primary and secondary, $E'_1 = 4.44\, n\, \Phi_m\, N_1\, 10^{-8}$, that part of impressed e.m.f. necessary to balance the counter e.m.f., $-E'_1$; $E'_2 = -E'_1$, the e.m.f. that would be induced in the secondary at standstill; s the slip, and $s\,E'_2$ the slip e.m.f. in secondary; $I_2 = \dfrac{s\,E'_2}{\sqrt{r_2^2 + s^2\,x_2^2}}$ = secondary current; $I_1' = -I_2$, that part of primary current necessary to balance the m.m.f. of I_2;

I_0 = the exciting current.

$I_1\sqrt{r_1^2 + x_1^2} = I_1 Z_1$ = impedance drop in primary.

E_1 = vector sum of E'_1 and $I_1 Z_1$ = primary impressed e.m.f.

There are two distinct interpretations of this diagram, one according to which the directions of the vectors represent the

relative time-phases of the several variables, and the other according to which the directions of the vectors represent the relative space-phases, in electrical degress, of the same variables. Clear conceptions of both interpretations are necessary to a thorough understanding of the problem in hand, but the latter will be particularly useful, since it is the space-phase of the exciting current that is determined by the brush position.

The power aspect of the problem is also a vital one, in which connection the following notation will be used.

$P_1 = E_1 I_1 \cos \theta_1 =$ primary impressed power per phase.

$P_1 = E_1' I_1 \cos (E_1' I_1) + I_1^2 r_1.$

$P_1 = E_1' I_1' \cos \theta_2 + E_1' I_0 \cos (E_1' I_0) + I_1^2 r_1.$

$I_1^2 r_1$ is the primary copper loss,

$E'_1 I_0 \cos (E'_1 I_0)$ the core loss, and

$E'_1 I'_1 \cos \theta_2 = E'_2 I_2 \cos \theta_2$

$$P'_2 = E'_2 I_2 \cos \theta_2 = \frac{s E'^2_2}{\sqrt{r_2^2 + s^2 x_2^2}} \cdot \frac{r_2}{\sqrt{r_2^2 + s^2 x_2^2}} = \frac{E'^2_2 s r_2}{r_2^2 + s_2 x_2^2}$$

Since P'_2 is the power transmitted across the air-gap from stator to rotor by the revolving field, it is a measure of the torque and is in fact the torque in synchronous watts.

One of the factors of the torque is E'_2 which in any given case is directly proportional to the flux, and the other factor is $I_2 \cos \theta_2$, the component of the secondary current in quadrature with the flux. This latter component will here be called the torque current, and will be designated thus: $I_\tau = I_2 \cos \theta_2$.

In a rough analysis, the flux and E'_2 may be assumed constant and the torque proportional to the torque current, I_τ. This will prove useful later.

Consider now the change necessary to be made in the induction motor diagram in order to adapt it to the Heyland motor, particularly to that form shown in Figs. 3 and 5.

In addition to the slip current I_{2s}, in the squirrel cage there will be a current I_s in the exciting winding which results from the combined action of two e.m.fs., one a slip e.m.f. in phase with $s E_2'$ (in fact equal to $s E'_2$ if, as is the case, the constants of the exciting winding have been reduced to primary turns), and the exciting e.m.f., E_c, whose relative phase is determined by the

brush position. For convenience, this current will be looked upon as two separate currents, which would be produced by the above two e.m.fs. if acting separately. Designate the current produced by the slip e.m.f. by I_{2s} and that produced by the exciting e.m.f. by I_c. Then I_2, the actual current in the exciting winding is the vector sum of I_{2s} and I_c. These currents are all shown on the right hand side of Fig. 7. The total secondary current, I_2, both windings taken together, is then the vector sums of I_{2s} and I_2, or as will be found more convenient, the vector sum of I_s and I_c, where I_s is the total slip current.

If I_{2s} and I_{2c} had been calculated separately for the particular machine under consideration, I_{2s} would have been found to lag a little more than as drawn, and I_{2c} a little less, owing to the relatively greater resistance in the latter; but their vector sum would have been the same. It is quite as accurate then to con-

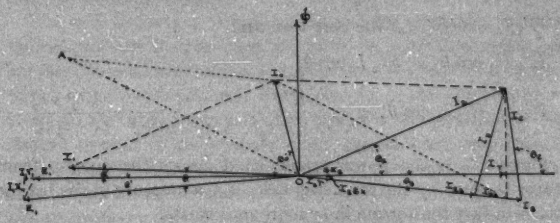


Fig. 7.
HEYLAND MOTOR.

sider these two windings as one, so far as the slip current is concerned, and to take the corresponding constants as given on page 773.

I_c is dependent entirely upon the exciting e.m.f. and the brush position. The reactance offered to this current is, as already explained, negligible, owing to the damping effect of the squirrel cage, and we may assume that I_c is in phase with E_c.

E_c is usually in quadrature with the impressed e.m.f., or at least bears a practically fixed phase relation thereto, being obtained from the same source by some transforming device.

Denote the space-phase of I_c by θ_c the angle which it makes with E'_2; this is not a fixed angle with fixed brush position, but nearly enough so for most calculations, and is far more convenient

than the angle between E_1 and I_c which is fixed with fixed brush position.

Assume now that the motor is running as an ordinary induction motor (see dotted lines of Fig. 7), on constant load. Then follow what takes place when a known exciting current I_c of known phase, θ_c, is delivered to the exciting winding.

The guiding fact in the determination of the new phase relations is that the torque current $I_\tau = I_2 \cos \theta_2$ will be practically unchanged. If θ_c is greater than 90° as in the figure, it is evident that I_s must increase beyond its corresponding value in a regular induction motor, *i.e.*, the slip must increase by an amount proportional to $-I_c \cos \theta_c$.

It is also evident that as the phase of I_2 is advanced by the introduction of I_c, the phase of I_1 will be similarly advanced, the amount of this advance depending upon $I_c \sin \theta_c$.

The exciting current has thus introduced two changes, one in the slip and slip current, proportional to $I_c \cos \theta_c$, and the other in the wattless component of I_1, proportional to $I_c \sin \theta_c$.

The latter change is evidently the important one, and to make it a maximum is to make the other a minimum, and $\theta_c = 90°$.

This is the usual arrangement. The effect of any change in I_c either as to its phase or magnitude is readily followed on the diagram. Results of tests in which various changes were made will be shown on a later page.

Of the two factors, magnetizing current and leakage drop, which go to introduce a wattless current in the induction motor, the former is approximately constant and the latter proportional to the load. It is thus impossible to compensate perfectly for primary lag at all loads, with a constant exciting current I_c. If I_c is just enough for no load compensation it will be insufficient at full load; if it just compensates at full load, it will over-compensate at no load and give a leading current.

The exciting current necessary for the complete compensation of this machine has been calculated for several loads and plotted in Fig. 8. One of the intermediate values of I_c will give a practically unit p.f. over the whole range except for very light loads. In this curve, as in later ones, the exciting current is plotted as it would be measured, amperes entering at one set of brushes, the theoretical ratio of this to the equivalent primary current is 1.79 and is obtained as follows:

One ampere from the compensator divides at the brush and becomes $\frac{1}{\sqrt{3}}$ amperes in each branch of the exciting winding.

This must be reduced to primary turns, and then by the differential factor, .866

$$\frac{1}{\sqrt{3}} \frac{24 \times 53.5}{16 \times 72} \times .866 = .557 \quad \text{and} \quad \frac{1}{.557} = .179$$

This calculation assumes sinusoidal currents and sinusoidal flux distribution in the air gap. Observations to be given below show that the real ratio is about 1.68.

Nearly all the points made in the above analysis, and some others, are illustrated in the tests recorded below.

General Conditions of Test.

Before considering the results of these tests it will be desirable to point out some of the conditions under which they were made.

The supply alternator was a General Electric 50 k.w. 3-phase 6 pole 60 cycle revolving-field machine with two slots per pole per phase. It is normally connected delta for 220 volts, but was connected star and raised to 440 volts for these tests. Its star e.m.f. is shown in Fig. 9_1.

The alternator was belted to an 80 h.p. single-crank, duplex-compound engine. The latter was new and its valves had never been accurately set, which aggravated the naturally large angular variation of this type of engine. This point was so forced upon our attention during these tests that later, when opportunity offered, the variation in velocity during a revolution when running light, was measured, and found to be about 3 per cent. on either side of the average.

The combined secondary resistance of the Heyland motor when running compensated, was so low that a very sudden change of 1 per cent. in the impressed frequency would have produced a change in the energy current amounting to about 60 per cent. of the full-load current.

After allowing for the various damping links between the engine and motor, there still remained a very annoying kick in the ammeter needles.

In addition to this rapid vibration of small amplitude, there

1. The fuzzy appearance noticed in this print is doubtless due to the warm weather and consequent fluidity of the damping oil, which allowed the oscillograph to inject a little of its own personality into the wave. It is safe to assume however that the longer kicks of larger amplitude, which appear in figure 4g have an entirely different origin.

was a larger swing of much longer period, due apparently to the sluggishness of the governor, and although the line voltage appeared to remain very constant, the exciting current as well as the primary motor current participated in the pumping.

Since the exciting circuit is almost a dead resistance, this was somewhat of a surprise, and the writer has looked in vain for a satisfactory explanation. The great steadiness of the line voltage and the comparatively slight flucutation of the wattmeter needles almost forces one to set aside the idea of a change of speed and an interchange of power between alternator and motor, and to look entirely to the motor itself as the origin of the difficulty.

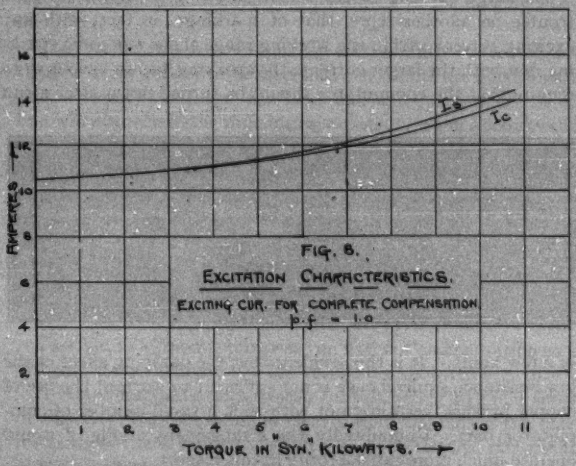


FIG. 8.

EXCITATION CHARACTERISTICS.

EXCITING CUR. FOR COMPLETE COMPENSATION p.f = 1.0

Whatever the cause, the exciting current did surge over a considerable range, and there was undoubtedly a corresponding change in power factor and line current, independently of any variation of the energy current; although that the latter did take place in a lesser degree was shown by the vibration of the wattmeter needles.

All these surgings decreased as the load increased, but varied from day to day, probably due to variations in steam pressure and belt tension. The latter was found by experiment to have considerable effect, but by no combination of conditions was it possible to eliminate the difficulty entirely. Another difficulty arose

from the heating of the exciting winding which caused the exciting current to decrease under constant exciting e.m.f. It was not possible to keep this current constant by means of an ammeter and rheostat, since the current in the ammeter includes a part of the slip current as above explained, and the latter varies with the load.

This variation of resistance was especially annoying in connection with the generator tests where the exciting current was necessarily much higher, and where a given change in resistance had a much more than proportional effect upon the terminal voltage.

The large exciting currents used in the generator tests gave trouble on another score, that of sparking; in fact, with any exciting current within the working range there was some sparking, but with the larger currents the sparking was so vicious as to require that the commutator should be turned down after a run

of a few hours. It is thus evident that the damping effect of the low resistance squirrel cage is not sufficient to warrant the use of copper brushes, certainly not with such a small number of commutator bars. Undoubtedly, the arrangement of Fig. 2 would operate much more satisfactorily in this respect.

The motor primary was star-connected and was provided with taps near the centre of the star, for excitation (see Fig. 3*b*).

There was also a separate star-connected compensator provided for the same purpose (see Fig. 3*a*). The latter was used in all the tests here described, as a much wider range of exciting e.m.fs. was thereby obtainable.

In all the motor tests there was an ammeter in each motor circuit and in each exciting circuit. Three wattmeters were used connected between the lines and the motor star, this arrangement better fitting the instruments at hand.

A single voltmeter was used across the line to maintain the

voltage constant, but the equality of the latter in the different phases was checked several times.

A single voltmeter and wattmeter were used in one of the star compensator circuits.

The slip was very accurately counted by the familiar alternating current arc lamp method.

The load on the motor consisted of a 500 volt direct current motor, operated as generator, and delivering current to a 500 volt generator as motor, on the shaft of the same engine to which the alternator was belted. This arrangement made it possible to obtain a very constant frequency, and very easy to control the load, although it undoubtedly contributed to the surging above described.

The instruments were frequently and carefully calibrated, and there is every reason to believe that the results are good for this class of work; but those who have had much experience in this line will appreciate the difficulties, especially when about twenty observations must be taken simultaneously by four or five observers. In this connection, the method above described for loading the motor had one great advantage, that it made it possible to keep the load perfectly steady throughout any desired period.

In all the motor tests the impressed e.m.f. was maintained at 440 volts.

Results of Tests.

Test No. 1.—The machine was run without compensation as an ordinary induction motor. The results are shown in Fig. 10.

A vector diagram drawn to scale for full load of 10 h.p. is shown in Fig. 11. This shows more clearly than the curves the phase relations of the severable variables, and the relative importance of the constants.

Test No. 2.—In this test the motor had no load except its own friction and that of the load-generator to which it was belted; the exciting e.m.f. was kept at an arbitrarily chosen value, 8.15 volts star, and the brushes shifted around a complete electrical circumference; readings were taken at regular intervals, the object being to find the magnetizing or normal position of the brushes, at which the power factor is a maximum and the line current a minimum. See Fig. 12.

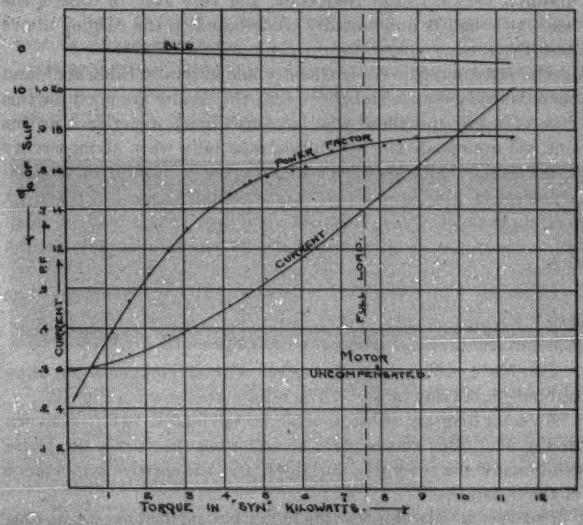
The observed points are marked and the solid curves are drawn in from approximate calculations in which the leakage reactances were neglected, the errors thereby introduced being compara-

tively small. The object of the calculations is that they may serve as a basis of interpretation for the observed results.

The broken curves, where drawn, are through observed points. The lower scale of degrees is the arbitrary one of the brush-rocker, and the upper degree scale corresponds to the angle θ_c of the diagrams.

The variation of the several quantities involved is most readily followed with the aid of the diagram, Fig. 13, which is drawn to scale. The notation is the same as in Fig. 7. I_o, I_r and I_c will

FIG. 10. TEST A1



be assumed constant but I_c may be shifted in phase by means of the brushes. The slip current is then $I_s = \bar{a}\bar{d} = I_r - I_c \cos\theta_c$ which in the position shown, is negative, *i.e.*, the motor is operating above synchronism. The primary current is $I_1 = \bar{d}\bar{f}$ and its power factor $= \cos\theta_1$ where θ_1 is the angle between $\bar{d}\bar{f}$ and the horizontal.

Of the total slip current a fixed proportion $\bar{a}\bar{b}$ flows in the exciting winding, and the remainder $\bar{b}\bar{d}$ in the squirrel cage. The total current delivered by the compensator is then the vector sum of I_c and $\bar{a}\bar{b}$, namely, $\bar{o}\bar{b} = I_s$. Given the slip current the slip may

be calculated as on page 1. It is easy now to follow the changes in the several variables, as I_c is made to revolve by shifting the brushes. The locus of the point b is shown by the inner curve in the diagram.

In calculating the curves for the slip and for I_3, the hot resistance of the squirrel cage was inadvertently used, whereas the current was so small that the squirrel cage was undoubtedly at a low temperature. Had the cold resistance been used, these two curves would have fallen nearer to the observed points.

The somewhat erratic disposition of the I_3 points is entirely accounted for by the change in temperature of the exciting windings; the points were not taken in consecutive order.

The considerable discrepancy between the calculated and observed values of I_1 and of the power factor, is partly due to the surging of the exciting current noted above, and partly to the

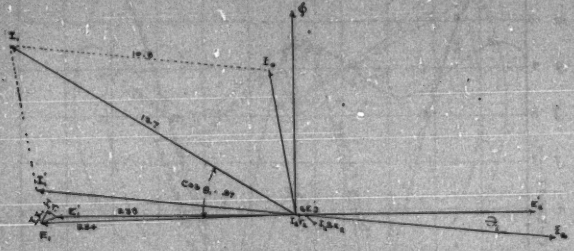


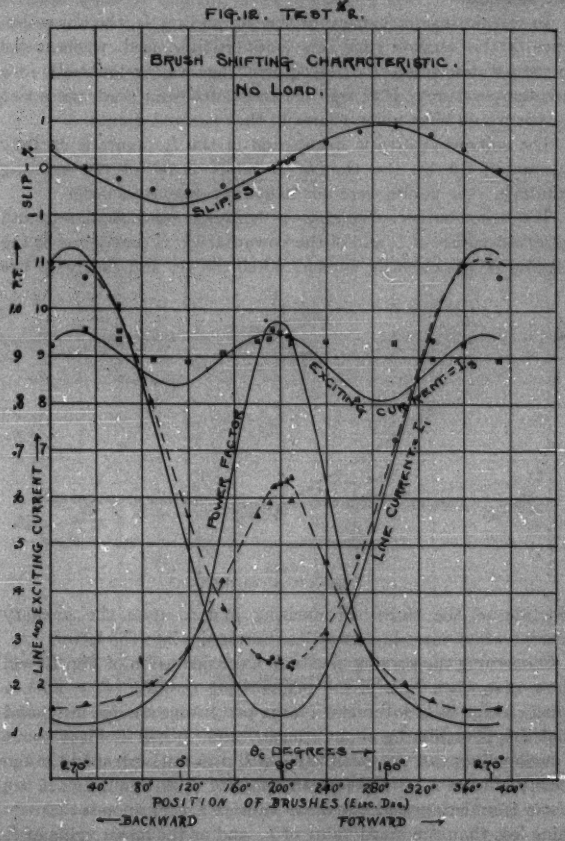
FIG. 11
SIMPLE INDUCTION MOTOR.

reaction of the three-belt exciting m.m.f. upon the primary current which introduces wattless harmonics into the latter.

Concerning the surging question, a consideration of Fig. 13 will show that when I_c is in the magnetizing position ($\theta_c = 90°$), a small change in I_c will make a large percentage change in I_1, and that if I_c is oscillating about a mean value, I_1 will oscillate about a mean value; but the mean value of I_c does not correspond to the mean value of I_1. If the mean value of I_c is small, *i.e.*, if the motor is under-excited, the mean value of I_c corresponds to something less than the mean value of I_1, and as the mean value of I_c increases, it corresponds to a value of I_1 which is less than its mean by an increasing difference, until the mean of I_c is equal to $I_0 \sin \theta_0$, when it corresponds to the minimum value of I_1.

If then the currents are surging as above described, and each

reading recorded is the mean taken over the range of oscillation, the records of I will be too large, the discrepancy being most marked in the vicinity of the highest power factor. The larger



the load the less this error, since an increase in energy component reduces the influence of the variable wattless component.

Concerning the wattless harmonics induced in the primary by the reaction of the exciting current, the simplest point of view is

to assume a sinusoidal flux distribution and to remember that the resultant m.m.f. of all three currents must be distributed sinusoidally. If one of the three is forced by the nature of its winding to give a very far from sinusoidal m.m.f., and if this one happens to be carrying a much larger current than the other two together, as is the case in hand, there will be induced in the other two windings, relatively large wattless harmonic currents, which neutralize the undesirable part of the exciting m.m.f.

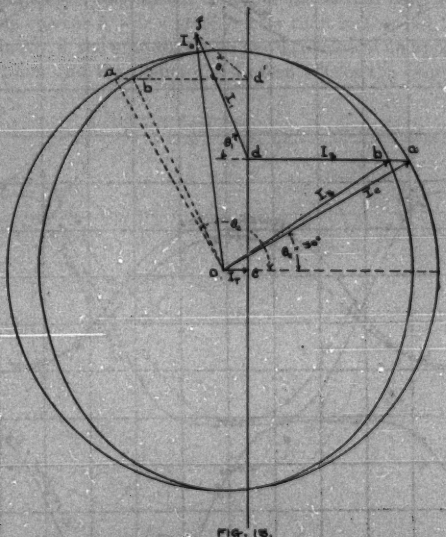


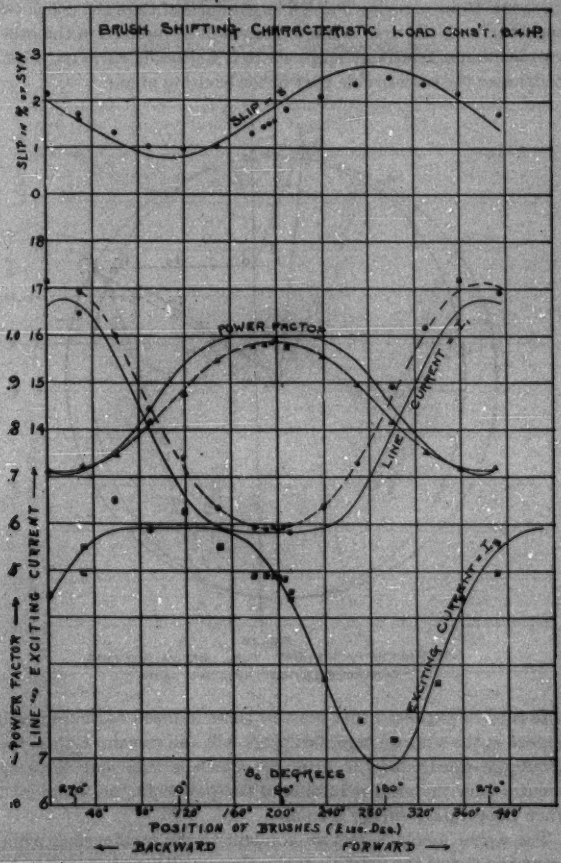
FIG. 18.
CONSTRUCTION DIAGRAM FOR BRUSH-SHIFTING CHARACTERISTICS AT NO LOAD.

It is to be expected that most of these induced harmonics will appear in the squirrel cage, but there will still remain in this case about one-fourth for the primary, which is sufficient to bring about a very material reduction of the power factor at no load when the primary energy is small.

The writer much regrets an accident to the oscillograph while preparing to test the validity of this theory, although there can be little doubt that this disturbance is quite appreciable at light loads.

As the energy current increases, the harmonics dwindle by comparison, so that at full load neither of the above mentioned disturbances are likely to introduce any considerable error.

FIG. 14. TEST 3



The same phenomenon is very prominent in a synchronous motor at light load; the shape of the induced e.m.f. wave is not the same as that of the impressed wave. It has been shown by

Rosenberg[1] that when current and e.m.f. are in phase, the power factor of a synchronous motor at no load is sometimes as low as .4.

The difference between the observed and calculated power factor and current, thus explained, appears in all the light load observations, sometimes more, sometimes less prominent, according to the amplitude of surging and the magnitude of the exciting current.

Test No. 3, *Fig.* 14.—This test was similar to No. 2, except that the motor was loaded to about its normal capacity. The exciting current I_e was a little greater than in Test No. 2.

As in No. 2, the solid curves show the results of an approximate calculation and the points and broken curves the results of ob-

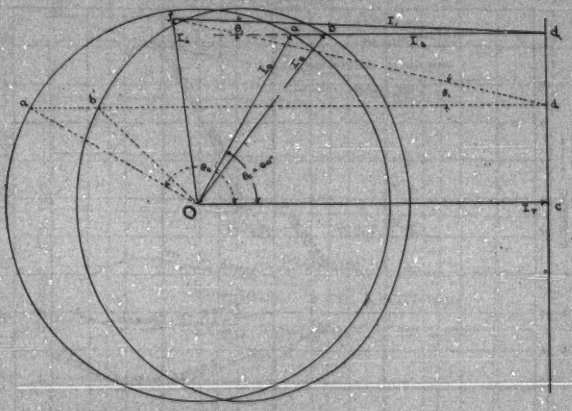


FIG. 13.

CONSTRUCTION DIAGRAM FOR BRUSH SHIFTING CHARACTERISTICS AT FULL LOAD.

servation. The approximate diagram drawn to scale is given in Fig. 15, in which the variation of the several quantities can be easily traced.

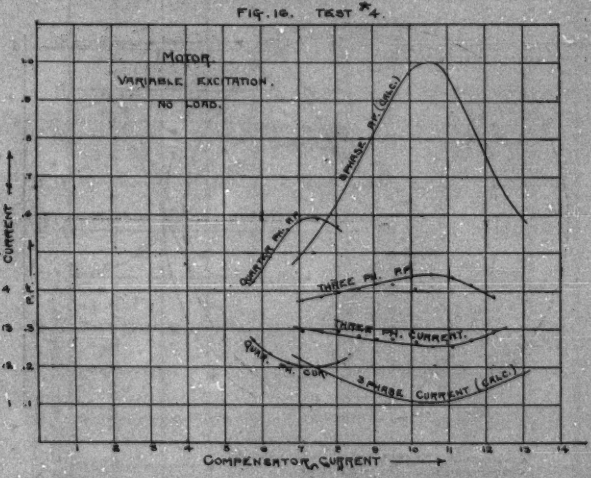
The slip being much greater, the slip current in the exciting winding, and therefore the variation in I_s will be greater. The slip never reaches zero in this case, since the exciting current is not large enough to relieve the secondary entirely of its large torque current, even when the former is in phase with the latter.

1. *E. T. Z.*, Feb. 12, 1903.

The discrepancy between the calculated and observed power factor and current is not nearly so great as in the no load case, for reasons already given, and the apparent discrepancy is due partly to the neglect of leakage in the calculations.

Test No. 4, *Fig.* 16.—In this case the brushes were left stationary throughout, in the magnetizing or quadrature position, determined by the preceding tests. The machine was running light, and the excitation was varied over a wide range. The line current and p.f. alone were plotted. These tests were made, one with 3-phase and the other with quarter-phase excitation.

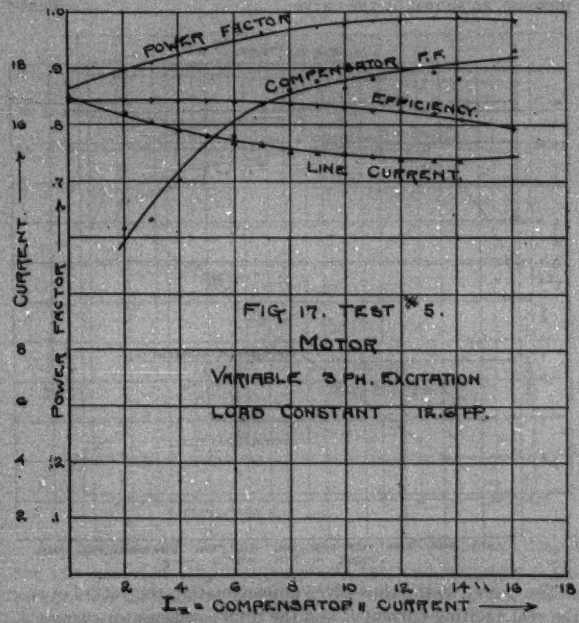
Power factor and current curves were calculated for the three-phase case and are shown in the figure.



Comparison of the observed and calculated results shows very clearly the marked effect of the surging and of the wattless harmonics in the primary. That the latter were present in this case is quite certain on two accounts: first, the lowest point reached by the ammeter needles in their swing was not low enough to correspond to a unit power factor; secondly, because the quarter phase excitation gave a considerably higher p.f. than the three phase. This is just what would be expected, since the m.m.f. harmonics are much less prominent in the quarter-phase four-belt winding.

Had these two tests been made on different days the above conclusion would hardly be warranted, as the degree of surging differed so much from day to day; but they were made at the same sitting, and there was no appearance of change in any of the conditions.

Test No. 5. Fig. 17.—This was similar to the preceding, except that the machine was heavily loaded. Three-phase excitation alone was used, and the brushes were kept in the magnetizing position.

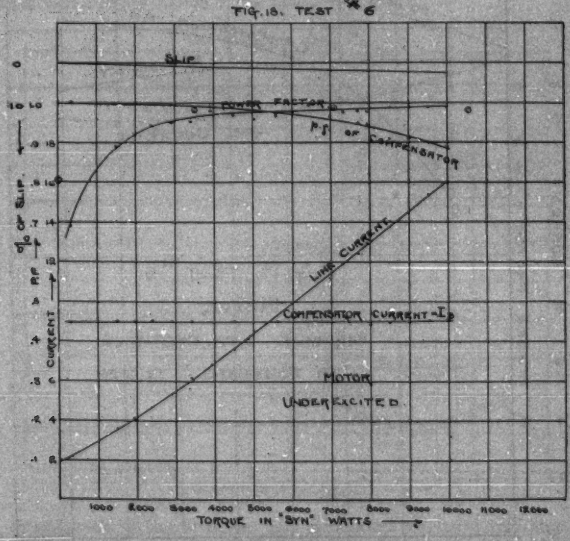


The power factor does not quite reach unity, showing even here a perceptible error due to the surging. It is not likely that the wattless harmonics have any appreciable effect upon the power factor in this case, when it is remembered that a power factor of .99 corresponds to a wattless component of .14, which would here be more than two amperes.

The *efficiency* curve in Fig. 17 shows that the copper loss in

the exciting winding more than balances the saving in primary copper loss, but this is also evident from a contemplation of the relative resistances of the two windings.

The curve marked " compensator power factor," shows the p.f. of the current delivered to the exciting winding, and would be approximately unity were it not for that part of the slip current which flows in this circuit. This slip current is approximately constant in this case, and in quadrature with the exciting current proper. Thus, as the latter increases, the power factor will increase, as shown by the curve.

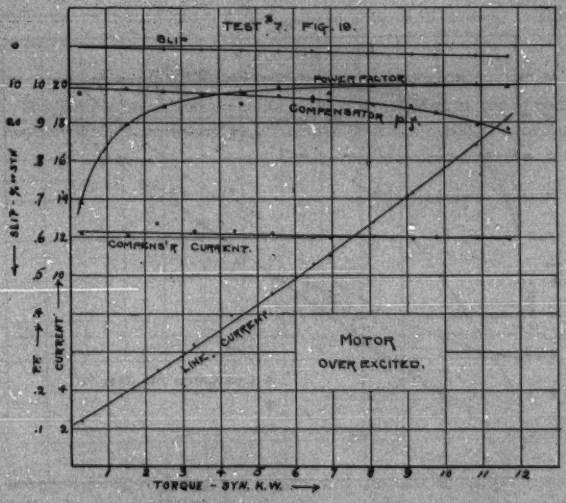


The power factor thus gives approximately the ratio between the real exciting current I_e and the total compensator current I_3, and since the curves of Fig. 17 are plotted against I_3, the latter must be multiplied by the compensator power factor, in order to give the real exciting current.

A comparison of this with the calculated excitation characteristic of Fig. 8 will show a good agreement as to the exciting current necessary to produce the maximum power factor at this particular load

Test No. 6, *Fig.* 18.—Exciting voltage and brush position both constant, load varied. As the excitation is low the power factor never reaches unity. The four points in large circles were calculated, and show that except at light loads the discrepancy is small. This is also true of test No. 7. In both of these cases there was much less surging at heavy loads than in most of the other tests.

The slip is less than in the uncompensated test, No. 1, owing to the added conductivity of the exciting circuit closed through the brushes.



The compensator current remains practically constant despite the increase of its slip component as the load increases. This means that the exciting current I_e decreases, due to the heating of the exciting winding.

The compensator power-factor is interesting, as it shows what has been demonstrated theoretically above, that near synchronism the reactance of the exciting winding is negligible. It also shows the decrease of the power factor due to the increase of the slip current in quadrature with the exciting e.m.f.

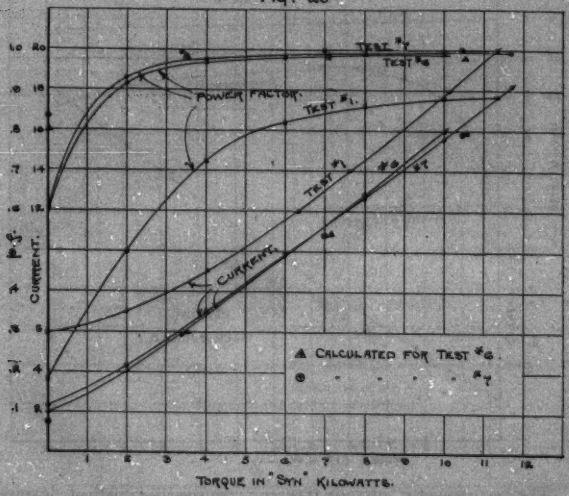
Test No. 7, *Fig.* 19.—In this test the motor was overexcited. The primary current leads at light loads, the power factor grad-

ually rising to unity and dropping a very little at the end. The calculated power factor points are shown again in large circles.

Owing to the larger exciting current, the winding heats more than in test No. 6, and the resulting decrease in exciting current more than balances the increasing slip current; thus I_s decreases slightly with load.

For clearness in comparison, the current and power factor curves of tests numbers 1, 6, and 7 are plotted together in Fig. 20. A glance at the calculated power factor points of Fig. 20 will show that it is quite possible to maintain the power factor of such a

Fig. 20.



motor very nearly at unity, throughout its whole working range, by means of a constant exciting voltage. But it should be remembered that very nearly unity is not unity, and that a deviation of 1 per cent. therefrom means 14 per cent. of wattless current, about one-third as much as with a 90 per cent. power factor. In other words, a compensated motor may have a beautiful appearing power factor curve and still absorb a considerable wattless current. This is probably what lead Mr. Heyland to say that a constant exciting current would give perfect compensation at all loads.

There is thus no question as to the calculation or operation of this type of motor, the power factor is entirely within control and it can undoubtedly be made to operate sparklessly, but the question is, will it pay to sacrifice the beautiful simplicity of the ordinary induction motor for a little saving of wattless current, for there is no gain in other directions, either in efficiency or in starting torque. These are the directions in which the consumer is interested; he does not care much about the power factor.

There will of course be time and places where the power factor is a sufficiently vital question to warrant the use of the compensated commutator motor, but it is the writer's opinion that the Heyland machine as motor will not find a large field of usefulness in this country.

The Heyland Machine as Generator.

If a simple induction machine while operating as motor in connection with a network, be connected mechanically to a prime

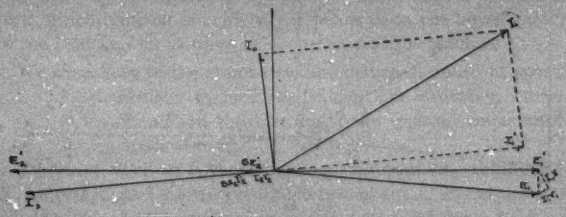


FIG. 21
SIMPLE INDUCTION GENERATOR

mover and driven above synchronism, the slip and slip-current will reverse, as will the energy component of the primary current. The machine will then be operating as generator, but with leading current (see Fig. 21). The amount of this lead depends upon the same factors upon which depends the lag in the induction motor, namely: the exciting current and the leakage. Such a machine can never be connected to a dead load but must be used where the wattless magnetizing current can be supplied by some synchronous machine connected with the system.

If now the machine in question be supplied with a magnetizing current through a separate winding and commutator, as above described, the lead of the primary current may be reduced in any

desired amount (see Fig. 22), where the current is brought into phase with the terminal e.m.f.. Assume that while thus operating without phase displacement the machine could be suddenly transferred from the network to a dead load of exactly the same magnitude (the exciting winding or the primary of its transformer being still connected to the machine terminals), it will continue to carry the load without change of voltage and will be a self-exciting shunt alternator. If now the external load resistance be decreased, the resulting increase of current will cause a larger drop, and the decrease in terminal e.m.f. will react upon itself through the excitation and flux, in a cycle very similar to that of the direct current shunt machine.

The end of this cycle for any given change of load resistance, depends upon the saturation curve as in the similar direct current

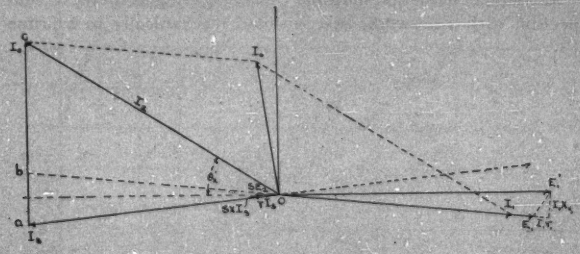


FIG. 22.
HEYLAND MACHINE AS GENERATOR

machine, but there is this difference: in the latter case that part of the drop due to armature reaction is dependent upon the brush position as well as upon the magnitude of the current, whereas in the machine under consideration the energy component of the armature reaction is balanced by the slip current, leaving a wattless demagnetizing component whose magnitude, in the case of a non-inductive load, depends upon the magnitude of the primary current and of the leakage reactance of both primary and secondary. This is best understood by a consideration of the diagram Fig. 22, where $\overline{o\,b}$ is a continuation of I_1 backwards.

In the case of an inductive load there is the additional quadrature component due to the reactance of the load. Then $\overline{bc}$ is approximately equal to the magnetizing component of I_0, which in turn is dependent upon E'_1. The total magnetizing current,

I_c, may then be considered as made up of two parts, $\overline{bc}$ consumed by the reluctance of the magnetic circuit, and $\overline{ab}$ required to balance the demagnetizing components of I_1 and I_2. These demagnetizing components are, in the case of a non-inductive load due to the leakage reactance in primary and secondary; but in the case of inductive load there is the additional wattless component due to the load itself. The lagging load has the additional effect of causing a greater drop between the internal e.m.f., E'_1, and the terminal e.m.f., E_1, as in the case of any alternating current generator.

In order to simplify the problem the demagnetising component of the armature reaction may be reduced to an equivalent armature reactance. Then the exciting current I_c may be considered as acting alone to produce a corresponding flux in the magnetic circuit and a corresponding e.m.f. in the primary, the relation between the exciting current and this e.m.f. being given by the saturation curve. Of this total induced e.m.f., E_0, a portion is consumed by the fictitious or apparent impedance of the armature, which impedance evidently depends upon the power factor of the load as well as upon the constants of the machine.

We then have in the shunt machine driven at constant speed,

E_0 dependent upon I_c as shown by saturation curve.

E_1 less than E_0 by the drop due to the apparent impedance.

I_c proportional to E_1.

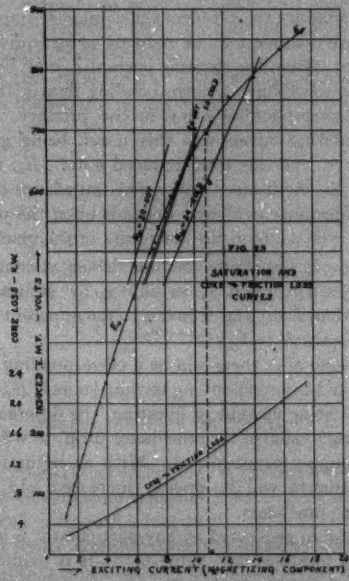
For every value of I_c there will be a corresponding total e.m.f. E_0 generated, and a corresponding terminal e.m.f., E_1, required to produce the exciting current in question, the difference between E_0 and E_1 being available for impedance drop, to which the current will be roughly proportional. With an inductive load the apparent impedance will be greatly increased and the corresponding current much less.

If however the E_0 generated by any particular I_c is less than the E_1 required to produce that value of I_c, it is evident that the machine will not operate at that point, even at no load.

These relations are shown more clearly in Fig. 23. The curve marked E_0 is the open circuit e.m.f. of the machine tested, plotted against the exciting current reduced to primary turns by the ratio 1.68 which, it will be observed, differs from the constant 1.79 worked out on the assumption of sinusoidal flux distribution. The constant, 1.68, was experimentally determined by comparing the saturation curves obtained from the machine as motor, and as generator on open circuit, both at 60 cycles.

The points marked with a circle were obtained by the former and those with a triangle by the latter method. The generator points were assembled from the no-load readings of a number of tests taken at different times and with slightly different brush positions.

The straight line, $N_{2c} = 24$, has for its tangent the resistance of the exciting winding reduced to primary turns and to primary volts, when 24 turns on the secondary of the compensator were in use. A similar description applies to the other straight lines.



The intersection of any one of these straight lines with the saturation curve gives the no-load e.m.f. corresponding to the exciting conditions represented by that line. The hot and cold resistance lines are given to show the great difference in terminal volts due to a change of temperature of the exciting winding.

For any given current the terminal volts will drop from the no-load value along the resistance line to a point b such that the vertical intercept $\overline{bc}$ is the impedance drop due to the given cur-

rent. The maximum current which the machine can carry for any given number of turns on the secondary of the compensator is thus determined by the maximum intercept $\overline{bc}$, between the corresponding resistance line and the saturation curve. As the p.f. of the load decreases, the apparent impedance increases very rapidly, and the corresponding maximum current decreases accordingly.

It is thus apparent that stable operation as a shunt machine cannot be secured below 600 volts, even for a small armature current, owing to the low densities in the magnetic circuit at normal pressures. The maximum densities in maxwell's per square inch at the normal e.m.f. of 440 volts, are approximately as follows:

E_1	440	800
Stator Core	32800	59700
Stator Teeth	49000	89000
Rotor Core	66200	120300
Rotor Teeth	49000	89000

At 800 volts, which is practically about the lowest safe running point as a shunt machine, the densities would be as given in the second column. The corresponding core loss is excessive as shown by the curve of Fig. 23, the natural remedy being a reduction of the rotor core section to such a point that the maximum rotor core density would be about 130000 at normal voltage.

The excessive pressures thus required in the generator tests were very troublesome in several respects. The correspondingly large exciting currents caused excessive heating of the exciting winding and made it practically impossible to get a complete set of readings without serious change in the resistance of this winding. The vicious sparking which accompanied the large exciting currents caused constant trouble at the commutator and such a wearing back of the brushes that, during a test of a couple of hours, they changed their location ten or fifteen electrical degrees. The condition of the commutator also affected the resistance of the exciting circuit.

Under these circumstances it can be readily understood why it was impossible to duplicate the conditions of any given test or to maintain the same conditions long enough to get a consistent set of results.

Fig. 24 shows four shunt characteristics the results of tests numbers 9, 10, 11 and 12. In each case the load was pushed to

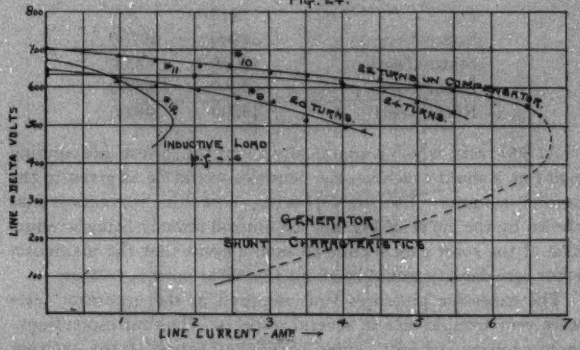
the unbuilding point which was considerably inside the current capacity of the machine.

In tests numbers 9 and 10, the machine was comparatively cold at the start and the droop of the characteristics is partly due to the heating of the exciting winding.

In test No. 11 the exciting winding was allowed to heat up before taking the readings, and the result is very apparent, for although 24 turns of compensator secondary were in use, the no-load voltage was lower than in the case of No. 9 with only 20 turns.

In No. 12 the power factor was about .6, and the machine started warm with 24 turns on the compensator secondary.

Fig. 24.



In each case the brushes were set in the magnetizing position, which is the same for motor and generator.

The slip was measured in one or two instances and found to agree entirely with the calculations, about .11 per cent. per ampere of energy current at 600 volts.

In all of these tests the machine was very unstable, and very sensitive to speed and to brush position, as might have been predicted from the saturation curve.

Compound Excitation.

Of the two parts into which we have divided the excitation, that part consumed by reluctance $\bar{b}\,\bar{c}$, Fig. 22, is dependent upon the total induced e.m.f. E'_1, of the primary, and is therefore required to increase only slightly with increase of load and con-

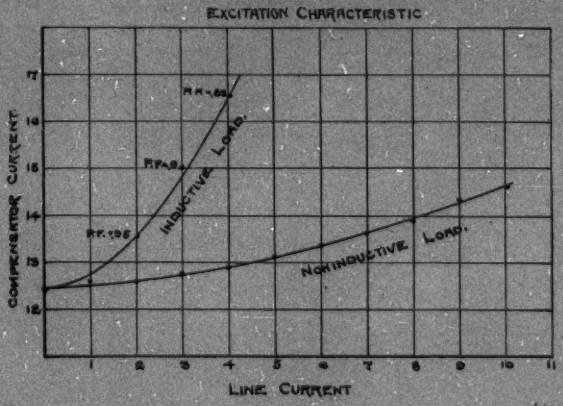
stant terminal e.m.f. The remaining portion, $\bar{a}\,\bar{b}$, due to the leakage, increases approximately as the square of the current, under non-inductive load.

Thus for moderately small non-inductive loads the demand for increased excitation is so small that a shunt machine will maintain an almost constant terminal e.m.f. over a moderate range. This is shown in Shunt Characteristic No. 11, Fig. 24, where the temperature of the exciting winding was constant. The smaller the leakage the farther out will the characteristics hold up.

This was probably what lead Mr. Heyland to say that the

FIG. 25. TEST #18

EXCITATION NECESSARY TO MAINTAIN E. = 550 VOLTS



shunt excitation gave perfect compensation with non-inductive load.

The excitation required for the complete compensation of this particular machine is shown in Fig. 25. The upper curve shows clearly the large increase made necessary by the reaction of the quadrature component of the lagging load current.

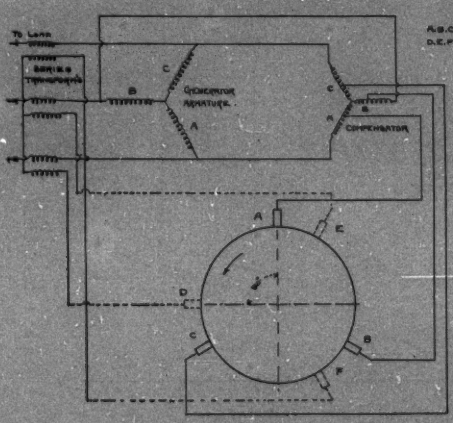
Hence the requirements for compounding are much as in the case of a synchronous alternator, except that owing to the relatively small reluctance m.m.f. in the induction generator, the percentage increase for inductive loads is considerably greater.

There are two distinctly different methods of compounding, one

in which the shunt exciting current above considered is increased by some arrangement of compounding transformers, and the other in which the shunt excitation is left as in the simple shunt machine, and the armature reaction completely balanced by sending the armature current, or some fixed proportion of it, into the exciting winding through a separate set of brushes about 90° from the shunt brushes.

The last mentioned arrangement is the one used by Mr. Heyland and is shown in Fig. 26.

Assuming that the ratio of transformation of the series transformer is such as to produce an m.m.f. in the secondary a little



larger than that of the primary, and that the brushes are so set that its space phase is exactly opposite to that of the primary, the slip-current will be supplanted, and together with the slip, will disappear, leaving a practically synchronous machine. The only function of the shunt excitation is then to supply the reluctance m.m.f. which is nearly constant. The slight increase in the latter, necessary to maintain constant terminal e.m.f., may be obtained by shifting the series brushes backwards a very little in order to throw a small component of the series excitation into the magnetizing phase. The result is perfect compounding for all power factors, as illustrated in Fig. 27, where the vector sum

of the shunt and series exciting currents is designated I_2, the total secondary current, and where the vector sum of I_1 and I_2 is a magnetizing current I_0, which increases slightly with the load.

The last paragraph is a statement of the theory of the method as ordinarily propounded, and assumes that the presence of the series current will not disturb the shunt current. With the arrangement employed in the tests here recorded, this assumption is not warranted.

This will be best appreciated by reference to Fig. 26, where A, B and C are the shunt brushes connected as indicated, and set in the magnetizing position, *i.e.*, in a position such that when the currents entering these brushes are in phase with their respective e.m.f's., these currents will supply an m.m.f. 90° in advance of the terminal e.m.f.

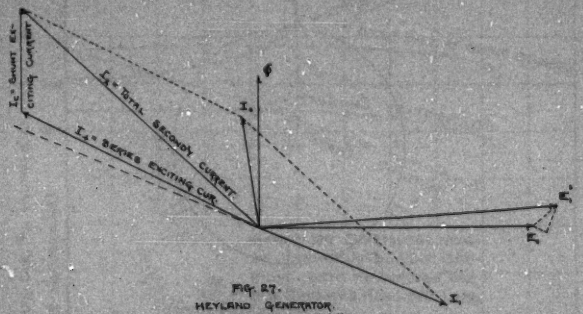


Fig. 27.
HEYLAND GENERATOR.
DIAGRAM FOR COMPOUND EXCITATION.

If the load is non-inductive and the series transformers connected to the series brushes D, E and F, as shown, the current entering the brush D will be of the same time-phase as the potential of brush A. In order therefore to place the m.m.f. of the series current in opposition to that of the primary current the series brushes must be placed approximately 90° in advance of the shunt brushes, as shown. But this places D, E and F only 30° behind C, A and B respectively, and since the potentials of the latter are fixed, it is evident from the proximity of the two sets that there will be a tendency on the part of C, A and B to control the potentials of D, E and F, and that the nearer the two sets the greater will be the degree of control.

The tendency of this control is to restrict the resultant current

to that which would flow under the action of the shunt e.m.f. alone, or since the series current is fixed in phase and magnitude, the shunt current will tend towards a value such that the resultant current will be as above described.

It has been explained above that in order to give the series m.m.f. a slight magnetizing component the series brushes should be shifted slightly backwards from the 90° position shown in Fig. 26; this would separate the two sets of brushes and make the two excitations more independent.

In the tests under consideration the following arrangement was used. The connections between the secondaries of the series transformers and the series brushes were reversed from those shown in Fig. 26, the other ends of the secondaries being con-

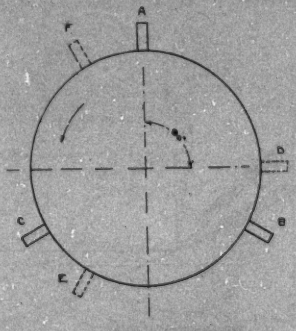


FIG. 28.

nected to the star and the ends shown in star connection carried to the brushes. This made it necessary to shift the series brushes 180° to the position shown in Fig. 28, so that the slight additional backward shift brought them closer to the shunt brushes, instead of separating them further as in the Fig. 26.

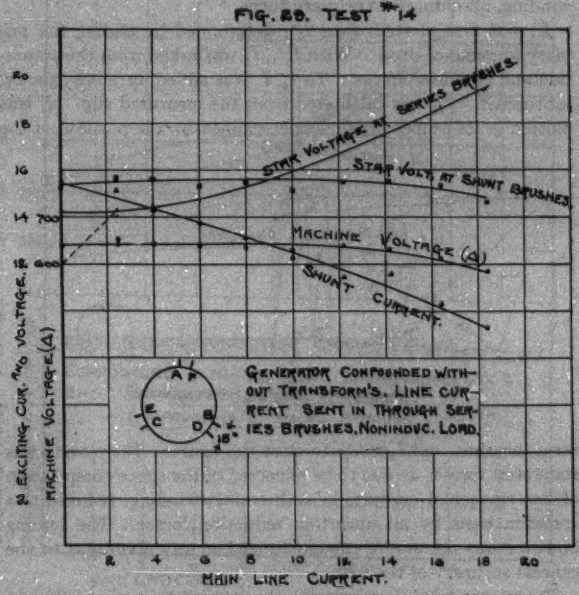
As the two sets of brushes were separated by a considerable angle (measured in mechanical degrees), the machine having six poles, the electrical proximity was not appreciated at the time of the tests.

It was found necessary in order to hold up the terminal e.m.f. under load, to give the series brushes an extra backward shift of from 25° to 50°, which would bring the two sets of brushes into practical coincidence on the two pole diagram, but always separ-

ated by an appreciable resistance in the actual machine, which had a six pole series closed coil winding.

The conditions were therefore such as to minimize the compounding effect of the series excitation. The appreciation of these conditions will assist materially in the interpretation of the experimental results.

Test No. 14, *Fig.* 29.—Load non-inductive. No series transformers were used, the series brushes being connected to the inner



ends of the machine star. The series brushes were placed 45° back of the slip position and 15° back of the shunt brushes, so that about 71 per cent. of the series current was thrown into the magnetizing position, but the resultant magnetizing current was nevertheless kept down by the proximity of the shunt brushes. Although thus restrained the compounding was sufficient to maintain a practically constant terminal e.m.f. up to the full load of 14 amperes.

A glance at the series and shunt e.m.f. curves will show the influence of the latter upon the former.

The phase relations of the several currents will be best appreciated with the aid of Fig. 30, in which are plotted to scale the current diagrams for three points of test No. 14. $\bar{of} = I_0$, the exciting current; $\bar{df} = I_1$, the primary current; $\bar{oa} = I_{2s}$, the slip-current in the squirrel cage; $\bar{ab} = I_{2s}$, the slip-current in the exciting winding; $\bar{ac} = I_s$, the actual shunt current; $\bar{cd} = I_4$, the series current; and $\bar{ad} = I_e$, the combined current in the exciting winding, all reduced to primary turns.

E_1 was first plotted, then E'_1 determined by adding the primary impedance drop. With E'_1, I_0 was taken from the saturation and core-loss curves. To I_0, I_1 was added, or more exactly, subtracted. I_{2s} was calculated from the measured slip. I_4 was plotted in its proper phase, as determined by the position of the

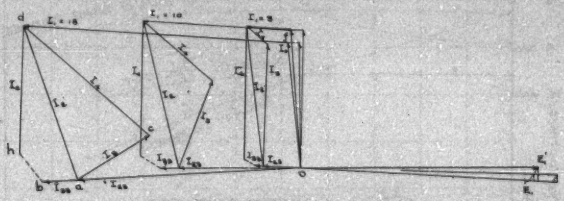


FIG. 30
DIAGRAM FOR TEST 14. (DRAWN TO SCALE.)

series brushes, and I_s made to close the figure. The closing was somewhat forced, as was to be expected of the space composition of non-sinusoidal currents in a three-belt winding, reduced to a common basis by an uncertain reduction factor. The forcing however was not severe enough to lead to any doubts as to the general accuracy of the data.

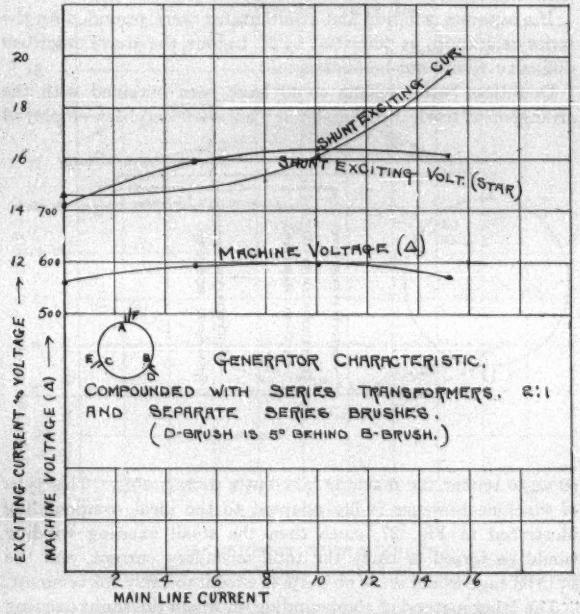
The vector $\bar{hd} = I_c$ represents the current that would flow in the exciting winding under the action of the shunt e.m.f. alone, the phase of I_c being determined by the brush position.

The total equivalent current in the exciting winding, I_e, may thus be considered as made up of a hypothetical shunt current I_c, dependent upon the shunt e.m.f., a slip-current $\bar{ab}$, and a current $\bar{bh}$ approximately in phase with and proportional to the series current, the constant of proportionality increasing with the electrical displacement between the two sets of brushes. When

the brushes of one set are just half way between those of the other, their currents should be practically independent of each other.

Test No. 15, *Fig.* 31.—Load, non-inductive. Series transformers, ratio, 2 to 1. D brush 5° behind B brush. The series current was thus twice as great as in test No. 14, but the greater proximity of the two sets of brushes reduced the proportion of the series current which was effective in compounding.

FIG. 31. TEST 15.



At the end of this test an inductive load with a power factor of .9 was tried, and by shifting the series brushes farther back the machine was enabled to carry 3.5 amperes. This was the largest inductive load that was carried during any of the tests. With the arrangement shown in Figs. 26, and a proper transformation ratio, the compounding would be more satisfactory; but it is very doubtful if the machine would even then maintain its pressure with an inductive load and fixed brush position.

With single-phase compound excitation, the series and shunt brushes would be 90° apart; *i.e.*, the series brushes would be half way between the shunt brushes, where the series current would least disturb the shunt current. This accounts for the fact noted by Mr. Heyland, that single-phase excitation was more satisfactory than three-phase excitation.

With quarter-phase excitation the series and shunt brushes would be practically coincident, and compounding for inductive loads impossible.

If a separate winding and commutator were provided for the series excitation, as described by M. Latour, the above described difficulty would not be experienced.

Doubtless better results could have been obtained with the arrangement used, if higher shunt excitation had been employed

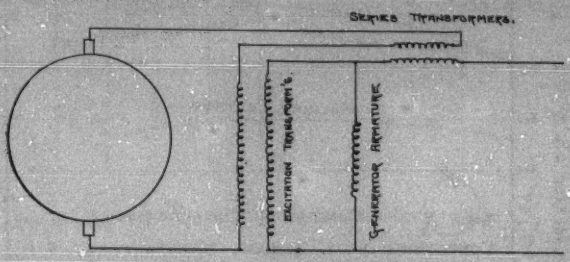


Fig. 32.

so as to render the machine inherently more stable. This type of machine however is illy adapted to the ideal compounding illustrated in Fig. 27, since then the small exciting winding would be forced to carry the total secondary current, and the squirrel cage would serve no purpose except to carry the remnant.

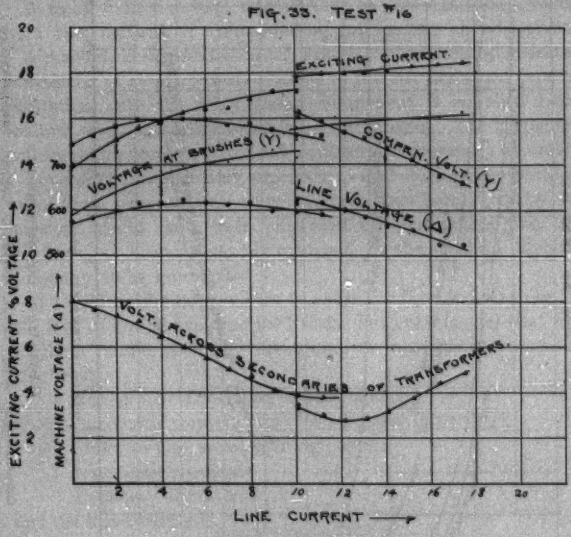
The other method of compounding, in which the shunt exciting e.m.f. is increased by an amount depending upon the phase and magnitude of the load, is much better suited to this particular machine.

Several more or less complicated arrangements are available, but the only one used in these tests is that shown in Fig. 32, its chief recommendation being its simplicity.

An open magnetic circuit transformer is inserted into each of the machine phases and its secondary connected in series with the

corresponding exciting phase. In order to avoid unnecessary complication, a single-phase machine is shown in the diagram.

The transformer introduces into the exciting circuit an approximately quadrature e.m.f. of magnitude proportional to the resultant of primary and secondary ampere-turns. At no load this quadrature component is in advance of the exciting current and is relatively large. As the load on the alternator increases, the reactive e.m.f. decreases and finally reverses; meanwhile the



effective e.m.f. at the brushes, and therefore the exciting current, increases steadily and also advances in phase.

The above assumes a non-inductive load; if however the load be inductive, the quadrature component of the load current will induce an e.m.f. in the secondary of the transformer which will be almost in phase with the exciting current.

Such transformers could be easily designed to compound for any given power factor, but would over-compound for higher and under-compound for lower power factors, assuming an induction

machine of ordinary proportions. If the machine had a long air gap, so that the percentage increase in excitation for inductive load were not so great, a fair compromise might be made for all power factors.

One of the drawbacks of this arrangement is that with fixed brush position the advance of the phase of the exciting current

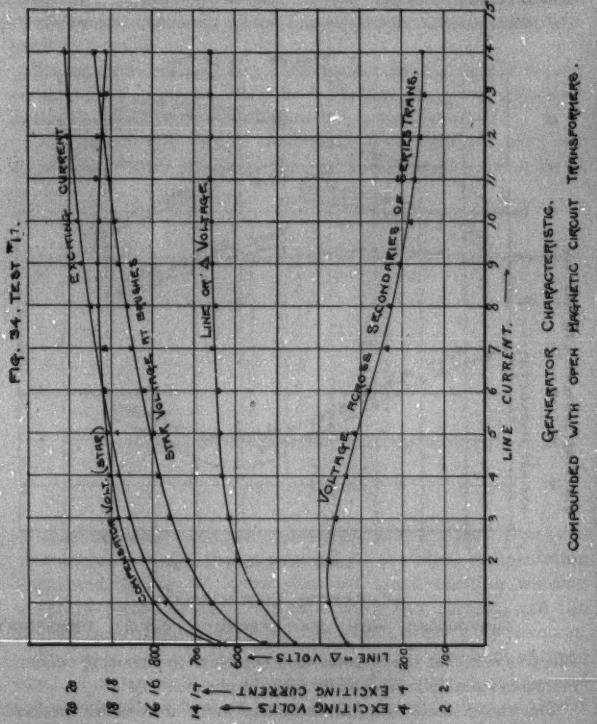


Fig. 34. Test 11.

Generator Characteristic.
Compounded with open magnetic circuit transformers.

causes an increase or decrease of its effectiveness according as the brushes were initially too far back or forward.

If set at the best full load position the no load e.m.f. will be low and vice versa. These points are shown clearly in the two non-inductive load characteristics of Figs. 33 and 34.

In the former case the brushes were set in advance in the best light load position and shifted backwards 15° for the last section of the curve.

In test No. 17 of Fig. 34 the brushes were set at the start in the best full load position, *i.e.*, in the same position as for motor or shunt generator operation.

The other curves are what were to be expected, the e.m.f. of the series transformer decreases to a minimum and then reverses sign.

A small inductive load was all that the machine could carry with this method of compounding, for reasons already given.

A machine compounded by the first described method operates practically at synchronism, whereas in the last described type of excitation only the magnetizing component is supplied from without, the slip current remaining unchanged. The frequency will therefore decrease with load, constant driving speed assumed.

Several of the questions which developed during the working up of these tests, answers to which have been here given by deduction, would have been answered by experiment had the machine not been previously returned to the General Electric Company to be remodelled.

It would be obviously unfair to judge the Heyland machine by the face of the above-described tests, but granting all that Mr. Heyland claims, the chief advantages of this type of alternator are, briefly:

Non-synchronous, ease of paralleling;
Automatic compounding for all power factors;
Short air gap, small exciting power;
No exciter required;
Economy of material;

and the disadvantages:

Commutator, this is prohibitive in low speed machines;
More complicated;
Much greater first cost per lb. of material;
Natural ventilation poor.

The automatic compounding is of little value in a large central station, and the exciting power cannot well be reduced below that of good synchronous machines.

The higher price of materials and lower price of labor in Europe may make a success there out of what would be very doubtful here.

The Heyland generator is naturally, for commutator reasons, a high speed machine with a small number of poles, and may

prove useful in connection with steam turbines, although the high commutator velocity may be troublesome.

In conclusion the writer wishes to thank the General Electric Company for the opportunity of making the tests above recorded, and to express his appreciation of the valuable assistance rendered by Messrs. Anderegg, Whiting, Snyder, Trowbridge, Burchenal and Willis, in connection with the taking of observations and the working up of the results, and by Prof. Kennelly in the final preparation of this paper.

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THE COMPOUNDING OF SELF-EXCITED ALTERNATING CURRENT GENERATORS FOR VARIATION IN LOAD AND POWER FACTOR.

BY A. S. GARFIELD.

A description of the characteristics of a polyphase alternating current revolving-field generator provided with a single closed-circuit field-winding and commutator. Effect of shifting brushes at various inductive and non-inductive loads, represented graphically.

The present discussion refers to polyphase alternating current generators comprising a stationary armature and a revolving-field structure provided with a closed-circuit winding connected to a multi-segmental commutator.

A description of the characteristics of the generator provided with a single closed-circuit field-winding and commutator will probably facilitate an understanding of the compounded machine.

Fig. 1 represents a bipolar machine of the first type, comprising a delta-connected armature-winding T and a field structure with commutator R; the ohmic resistance of the closed-circuit field-winding being suitably designed with reference to the induced voltage at the armature-terminals in order to obtain the required ampere-turns in the excitation circuit.

The position of the commutator brushes relative to the armature-terminals is represented by the angle A o a, the frequency of currents induced in the armature by N and the constant angular speed of the field structure, R, by S.

If the machine is now run without load and with the brush position determined by

A o a $= \pi/2$ we will have N $=$ S
or A o a $< \pi/2$ we will have N $<$ S
or A o a $> \pi/2$ we will have N $>$ S

The most interesting brush position is that represented by $A o a = \pi/2$, the angular speed of the field structure then being equal to the frequency of the induced armature currents.

With the brushes in any position whatsoever, if the machine is loaded we have:

1. A diminution in frequency of the induced armature currents.
2. An increase of current in the closed-circuit winding of the field structure R.

Whenever load is removed with the brushes in any position whatsoever we have:

1. An increase in the frequency of the induced armature currents.

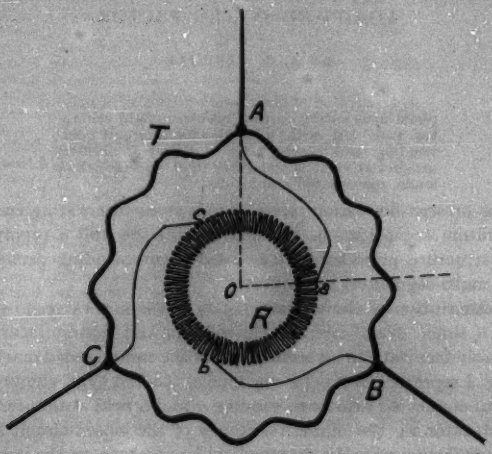

Fig 1.

2. A diminution of current in the closed-circuit winding of R.

With the brushes in any position whatsoever, that is, with $N < S$, or $N = S$ or, finally, $N > S$ and when the machine is without load we find, neglecting magnetic leakage, no armature reaction for induced currents with unit power-factor but the usual amount of reaction for wattless-currents.

If the brushes are moved:

1. In the direction of rotation, N increases.
2. In the opposite direction, N diminishes.

It is evident, therefore, that we can obtain for any load by a suitable change in position of the brushes:

$$N < S, N = S, N > S.$$

With the brushes in the position represented by $A\,o\,a = \pi/2$ at no load, we can always maintain $N = S$ by changing the brush position proportionally to the variations in load.

The following brush positions are interesting:

1. With the brushes placed so that $A\,o\,a = \pi/2$ for any load whatsoever, we will find $N = S$ at no load and $N < S$ when loaded. This is the characteristic operation of an induction generator.

2. The brushes may be set in a position corresponding to $A\,o\,a > \pi/2$, so that at no load we have $N > S$ and at full load $N = S$.

3. The brushes may evidently be set so that we have $N = S$ at any predetermined load.

In order to avoid the short-circuiting current in those sections of the field-winding connected to the commutator segments covered by the brushes, it is evidently necessary constantly to change the brush position in such a manner that N remains equal to S. If $N = S$ at no load, the same relation will be obtained with increase in load by moving the brushes forward in the direction of rotation of the revolving field. Under these conditions the frequency of currents induced in the armature will remain constant and the magnetic field fixed in position with reference to the inducing member.

In any event the variations in frequency will be of the same magnitude as the slip in well designed induction motors.

The graphical representation of these facts may be of interest. In Fig. 2, O R represents the ampere-turns of the field-winding, O T those of the armature and O F the resultant ampere-turns. $T\,O\,D = \varphi$, the phase-angle between current and e.m.f. The brush position $A\,o\,a$ corresponding to $N = S$, is represented by the angle D O R of Fig. 2. The magnitude of this angle evidently depends on the output of the machine and power-factor of the load, or, in other words, it varies proportionately to the inductive and to the non-inductive load on the machine.

Any variation in the inductive or non-inductive load will evidently leave the brushes in a defective position and if they were placed to give $N = S$ we will now have $N \lesseqgtr S$. In consequence of this an electromotive force proportionate to $N - S$ or $S - N$, as the case may be, will be induced in the field-circuit. When $N = S$ the impressed voltage $o\,d$ at brush terminals $a\,b$,

$b\,c$, or $c\,a$, which is the same as the induced voltage between terminals A B, B C or C A, counterbalances the ohmic drop O e in the field-circuits, including therein the drop in the brushes and brush-contact with the commutator. This ohmic drop is proportional to the ampere-turns O R of the field winding.

Referring now to Figs. 3 and 4 in which it is supposed that the brushes have a defective position A $o\,a \leqslant$ D o R, the impressed voltage O d at brush terminals will be represented in such a direction that D $o\,d =$ A $o\,a$ (either in advance of or behind the

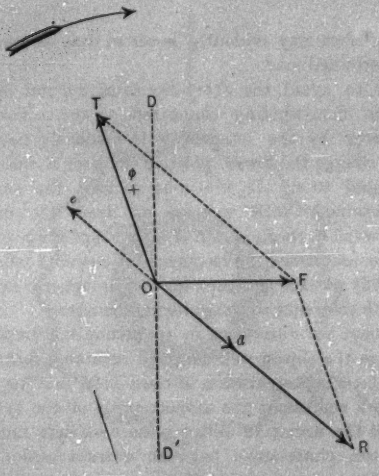

FIG. 2.

line O R.) This impressed voltage, O d, must be equal in magnitude and opposite in direction to the resultant, O g, of the ohmic drop, O e, in field winding, brushes and brush contacts and of the electromotive force, O f, induced in the field winding as a consequence of the modification of the relation N = S. If D $o\,d <$ D o R, O f, representing the magnitude of the voltage induced in the field-winding must be laid off, as shown in Fig. 3, and the frequency of the currents induced in the armature will be diminished. With D $o\,d >$ D o R,

o f must be represented as in Fig. 4 and the frequency of induced armature-currents will be increased. Any decrease in the inductive or non-inductive load on the machine corresponds therefore to an increase in frequency, and an increase in non-inductive or inductive load brings about a diminution of the frequency of the armature-currents. It is evidently possible to place the brushes in such positions as to ensure N = S at no load, half-load, full-load or overload, but in all cases the above-mentioned phenomena

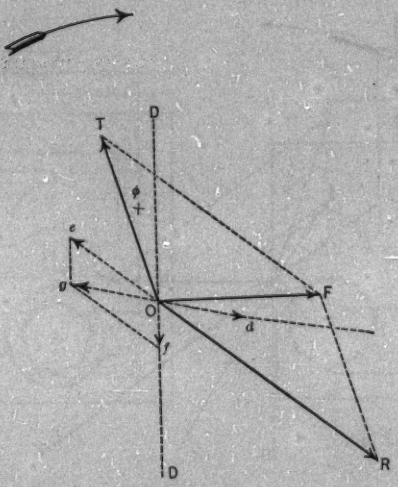

FIG. 3.

will be noted. Assuming the machine to work with a constant wattless output and the brushes set for a certain load to give N = S, any variation in the load will result in the points d, and g of Figs. 3 and 4, remaining fixed in space, the points T and e being displaced parallel to D D′, and the point f will be displaced along the line D D′. The machine will operate at constant terminal voltage but at variable frequency. The speed of rotation of the field structure has of course been assumed to be constant in the discussion.

Whenever a machine of the above description is connected to a network of given frequency, N, the brushes are set permanently in a fixed position, there is evidently a certain angular speed of rotation, N_1, of the machine, inferior, equal, or superior to the speed N which corresponds to the non-inductive no load output of the machine. The machine will take on load proportionally to the increase in speed above N_1, that is, to $N_2 - N_1$, where N_2 represents the speed of rotation of the machine when

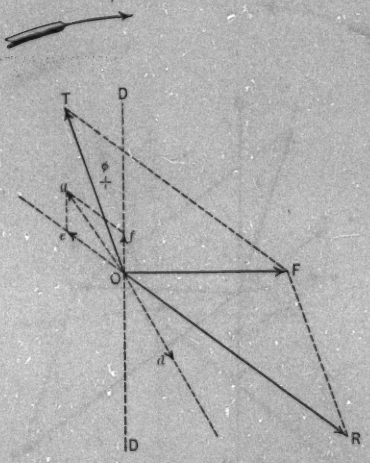

FIG. 4.

loaded. The wattless output of the machine will remain constant for all values of N_2. When it is zero, the machine operates with unity power-factor. The brushes would usually be set in a position to ensure $N_2 = N$ for the average load to be carried by the machine.

The machine would not be built as shown in Fig. 1, where the field excitation circuit is directly connected to the armature terminals, because of constructional difficulties consequent on the

enforced use of fine wire, etc. Step-down transformers may be used to reduce the machine voltage to a value convenient for use in the excitation circuit or an auxiliary winding may be used on the armature to obtain the most suitable excitation voltage for the field-circuit. In practice the excitation is arranged for more than three phases.

An alternating current generator of the above described type would find few applications, but it is easy to arrange for the compounding of this machine and it will then prove to be a very

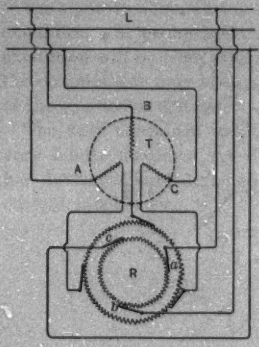

FIG. 5.

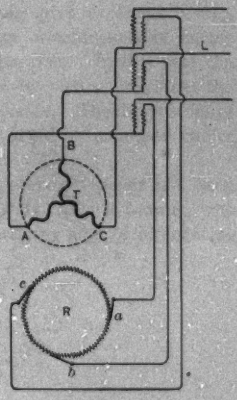

FIG. 6.

interesting type of alternating current machinery, especially in steam-turbine groups.

Consider for a moment the machine represented by Fig. 1 with the brushes fixed in the position corresponding to $A\,O\,a = \pi/2$. Place a second field-winding on the revolving-field and connect it to a second commutator provided with three sets of brushes connected to the armature-winding at points 120° apart, as shown in Fig. 5. These brushes are now to be fixed in such a position that the ampere-turns of this second field-winding oppose those of the armature; and we can arrange matters so that the armature-flux will be opposed by a field-flux of the same magnitude, direction

and form. A similar arrangement has been proposed by Mr. H. J. Ryan for continuous-current dynamo machinery.

With a machine constructed as above and with the brushes in a fixed position, we will obtain constant frequency of induced armature-currents and the machine will compound for variations in output and power-factor of load—in one or all of the phases.

The same result may be obtained by substituting for the second field winding, commutator, brushes, etc., three compounding transformers, one per phase, as shown in Fig. 6.

By means of these modifications the simple machine of variable frequency has become a constant-frequency machine, which result

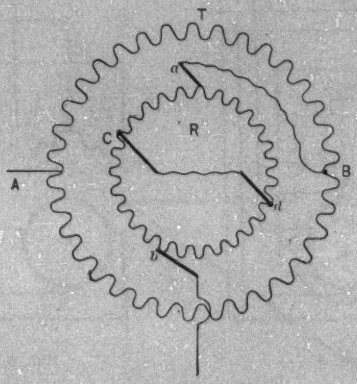

FIG. 7.

could only be attained in the first instance by changing the position of the brushes for variation in non-inductive and inductive loads.

A single-phase simple and compounded machine may be obtained by using two short-circuiting brushes placed at right-angles to the brushes connected to the armature-winding. The same arrangement with armature and field connected in series as shown in Fig. 7, is especially interesting in single-phase traction motors, but the discussion of this line of single-phase machinery is reserved for a future paper.

In view of the probable objections to the use of a commutator in alternating current machinery, it is of interest to note that the commutation is perfect on all the machines which have been tested. Any pulsations in the magnetic flux of the machine are dampened by the field-winding, which is practically short-circuited on the armature-winding by means of the brushes thus constituting a damping-coil. Furthermore, the currents induced by pulsation in the magnetic flux in those positions of the field winding circuit which are short-circuited under the commutator brushes assist energetically in dampening these pulsations. Machines of 50 cycles, 30 to 40 kilowatts output with twelve coils and six commutator segments per pole, give excellent results with three-phase excitation. In large machines it is better to use eighteen commutator segments per pole. In this case the excitation will be hexaphase. In low-frequency machines the excitation will be from seven to nine phases. The dimensions of the commutator may always be made small by a proper choice of the excitation voltage.

The data contained in this hastily prepared paper has been very kindly placed at my disposal by Mr. Marius Latour, who has developed and designed this interesting line of alternating current machinery.

Discussion

President Scott:—The subject for the meeting this evening is the general subject of Induction Generators. The main paper on that subject, the leading paper, unfortunately, has not been prepared, so that the title of the subject to be considered has been disregarded, and we take up several papers relating in general to alternators.

In its simplest form the dynamo consists of an armature and field. The field may be a permanent magnet; it may be an electromagnet. The great evolution in electrical machines came in the introduction of the electromagnet as a part of the field. Ordinarily, the field is a very simple part of the machine excited by direct current, and the variations in the character of the machine, direct current or alternating current, its voltage, its phases, frequency, etc., are dependent on the armature, but there are variations which can be effected in the field itself. The field may be excited by direct current, it may be excited by alternating current; the field magnetic flux may come from the currents which flow in the armature, coming from some auxiliary source. If the field be supplied with an alternating current, we have a new set of relations different from those which we have when the field is excited by direct current. The field alternating current may have different frequencies; may be of a low frequency. The alternating current in the field may be derived from some external source; it may have some synchronous relation with the main frequency. Here, then, we have a variety of conditions for exciting the field by alternating current, and derived from different sources, or by deriving the excitation from a current flowing in the armature itself, which give a new field, a new order of investigation and development and operation to alternating machines.

In one of the simplest forms comes the ordinary induction motor, with a squirrel-cage secondary. That may be used as a dynamo, if the speed be a little above, instead of a little below, the synchronous speed. Again, in the field of an alternator, there may be means for compounding, for increasing the field strength by a current derived from the main current. This gives a new order of relation, so that we have a very interesting and somewhat complicated and intricate set of problems arising from field variations in alternating machines.

The papers this evening have in one phase or another to do with the general problem which I have presented in this meagre and brief way. The first paper of the evening is by Mr. Behrend, who has given much attention to the designing, principles, theory and testing of alternating apparatus. The subject of Mr. Behrend's paper is "The Experimental Basis for the Theory of the Regulation of Alternators."

Mr. Behrend:—Midnight is drawing near and we have before us eighty pages of complex and intricate matter, and I

presume that we do not wish to extend this meeting until the Niagara Falls convention. In justice to the papers that will be read after mine, I want to be brief. I sincerely trust that this will meet entirely with your approval.

(Mr. Behrend then presented an outline of his paper.)

I want to call your attention to one or two matters which I have not had an opportunity to take up in my paper. The great importance of specifying the regulation of alternating current generators in regard to the size, efficiency, operation and cost of the machines is not at all clearly understood by consulting engineers. Besides, we often find specifications calling for conditions which are impossible to fulfill, as they are mutually contradictory of one another. For instance, you can find specifications calling for a regulation of 5 per cent. on a 100 per cent. power-factor, and a regulation of 12 per cent. on an 80 per cent. power-factor, and an increase of excitation of 10 per cent. between normal voltage at no load and normal voltage at 80 per cent. power-factor. Such things are impossible. I have tried to take this matter up in my paper with a view to pointing out a method by which you can convince yourselves as to what conditions are possible to obtain. Furthermore, a regulation which is too good may lead to a low efficiency of the machine and a poor operation in parallel on account of the large cross-currents which would be produced with reciprocating engines.

PRESIDENT SCOTT:—I had the pleasure when in Paris last summer of meeting a young man about my own age, a bright, intelligent man, who looked not unlike an American in his general make-up. He appeared to be a progressive man and probably possessed considerable skill as an experimenter. I was very favorably impressed in meeting him. The gentleman to whom I refer is Mr. Heyland, and the next paper relates to the Heyland motor. Prof. Comfort A. Adams, of Harvard University, will now present the second paper, "A Study of the Heyland Machine as Motor and Generator."

PROF. ADAMS:—I feel considerable diffidence in bringing this paper before the INSTITUTE, partly because the results obtained by experiments which are recorded here do not seem to be of very great practical importance, and partly because the volume of the paper might lead to unlawful expectations. Some one has said the paper looked very attractive. I hope that some of you who take pains to read it will find it attractive, but it is not a subject which is, in detail, probably interesting to the majority of the members of the INSTITUTE, but it has some practical bearings, and as such I hope it will be of some interest.

PRESIDENT SCOTT:—We have had this peculiar alternator problem attacked from various points of view. First, a designer told us a few things he knew about the alternator, and then we have had a Professor who has told us what he knows about it, and now we have another point of view, and that is the point of view of the direct current man who has assumed, we may say,

to know nothing about it, and yet to pronounce judgment upon it. The next paper is by Mr. A. S. Garfield, who writes on "The Compounding of Self-excited Alternating Current Generators for Variation in Load and Power Factor." The writer of the paper is not present and it will be abstracted by one of our members who is an expert in the direct current business, Mr. Gano S. Dunn.

MR. DUNN:—I am sure President Scott wants this abstract to be short. That is why he called on me.

Mr. Dunn then abstracted the paper. (See page 811.)

PRESIDENT SCOTT:—I notice in the list of applicants for admission as an associate of the INSTITUTE the name of Marius Latour, Paris, France, to whose apparatus mention has been made.

The subject is now open for general discussion if any one is pleased to take part in the discussion.

PROF. ADAMS:—I would add one word to Mr. Behrend's paper which is very interesting to me, dealing with a subject to which I have given much attention. I have made very careful tests on several large machines and on numerous small ones, of various types, and the results are entirely corroborative of Mr. Behrend's results. The e.m.f. method gave almost invariably too poor, and the m.m.f. method too good a regulation. In machines of the inductive type, reactance plays a larger part than armature reaction, and here the e.m.f. method is more suitable, since it is essentially a reactance method; whereas with machines in which armature reaction predominates, as in the modern low frequency alternator, the m.m.f. method is more suitable; but even when the method is chosen to suit the type of machine, the results are very wild, and some compromise between the two methods must be employed.

MR. WILLIAM L. WATERS:—Clause 71 in the Recommendations of the Committee on Standardization, which deals with the regulation of alternators, is, I think, more or less of a makeshift and a confession on the part of the Committee of their inability to formulate an exact method of determining the regulation of an alternator from any other than a full load test. It is well known to every designer that the method therein indicated gives results which, on certain classes of machines, are far too low. I do not know of any accurate method which can be substituted for that load.

By far the best method in guaranteeing the regulation of an alternator is to guarantee it for a low power-factor. As regards the actual operation of the machine, this is far more satisfactory than guaranteeing the regulation on non-inductive load, and in addition it is an easier test to make. By running a test, as described by Mr. Behrend, with two machines, one running as a synchronous motor and the other as a generator, and then adjusting the excitation, a direct reading for the regulation can easily be obtained. This test can quite easily be made even on very large units.

As regards the advisability of having the regulation guaranteed for low power-factors, even in the case of alternators for running rotary converters, I will give an instance of trouble that occurred in a large station with alternators supplying power for rotaries in substations. A breakdown occurred on the high-tension leads of the alternators, causing a temporary shutdown of the plant, so that when the alternators were again run up, the rotaries had to be started from the alternating current side. As soon as the voltage showed up again in the substations, all the attendants threw on their rotaries at the same time, and the result was an immense lagging current, which cut down the volts so that the rotaries refused to start. The attendants seeing this, cut out their rotaries and the volts rose again. This went on two or three times, and in the end it was about three-quarters of an hour before the substations were started again. These alternators had a guaranteed regulation of 7½ per cent. on power-factor 1, and that would satisfy this guarantee if tested according to INSTITUTE rules, but their behavior on low power-factors can be imagined from the above incident.

Coming to Mr. Behrend's paper, he points out very well, I think, that the two empirical methods which he gives for determining the regulation are neither of them accurate, and every designer has to modify these methods in order to obtain satisfactory results on his own individual machines. But I think Mr. Behrend begs the whole question when he uses the Kapp diagram to calculate the regulation on different power factors, assuming the regulation from power factor 0. The Kapp diagram assumes that the self-induction of an armature remains constant for all phases of the armature current, that is, for all relative positions of the armature and magnets. This is a pure assumption, and is in reality by no means correct. Some years ago I did some work on this method of obtaining the regulation of alternators, and measured the self-induction of the armatures of a large number of alternators for different relative positions of the armature and fields, the measurements being made with short-circuited magnet coils. I found that the self-induction varied very considerably according to the relative position of the armature and magnet, and with some machines of very small air gap this variation was of the order of 6 to 1. These measurements, of course, do not accurately represent the condition of things under load, but they give some idea as to the variation that may take place.

Mr. Behrend closes his paper with an application to direct current machines of this short circuit method of measuring the armature reaction, and gives an instance in which this gave pretty accurate results. This method of determining the compounding on a direct current machine is very old, and was used with fair success on the old smooth core armature machines. But in modern slotted armature machines with highly saturated teeth the distortion of the fields as caused by armature reaction

makes a large increase in ampere-turns necessary on full load in order to overcome the decreased permeability of the armature, due to this distortion. So that though this method may give fairly good results in a machine in which the tooth density is not over 125,000, it will be very inaccurate in a machine with highly saturated teeth, say a machine with teeth worked at 150,000. The compounding ampere-turns necessary in this latter case would probably be about double that given by the short-circuit method.

MR. BEHREND:—I was very sorry that I had no opportunity to refer to Prof. Adams' very interesting papers in the Harvard *Engineering Journal*. Prof. Adams was so kind as to send me a copy of his papers which, however, did not reach me until a day before I left Cincinnati for New York, otherwise, I should have taken great pleasure in referring in my paper to his work along the same lines, as I entirely agree with the results obtained and the methods in his paper. I deem it a pity that papers of such quality are not published in our TRANSACTIONS, but in journals like the Harvard *Engineering Journal*, which do not, as a rule, come to our notice. We might add such papers to the very long list of the papers we have to read, but few of us can find time to read the journals that we already have.

In regard to the remarks of my friend, Mr. Waters, I think he pointed out one of the principal weaknesses of my paper. He said that I arbitrarily applied the Kapp diagram to the determination of the regulation at different power factors. It is perfectly true that this is more or less arbitrary, but, as we are continually floundering in a maze of assumptions that are more or less arbitrary in regard to the conditions under which machines have to operate, and in determining their exact dimensions, we have to use engineering intuition to tell us how far we are justified in making such assumptions. I have pointed this out in my paper to-night and I have pointed it out invariably in my other papers treating of matters connected with electrical engineering, and especially in my treatise on "The Induction Motor." Electrical engineering, in my mind, is an art and not a science. As you cannot teach any one to make a good picture if he has not the aptitude, so you cannot teach a man how to design an electrical machine. It is a question of engineering judgment and intuition. If engineering methods, as set forth in my paper, fall into the hands of men without judgment, the results are the same as if you put a knife into the hands of a bungling surgeon.

[COMMUNICATED AFTER ADJOURNMENT BY J. R. ARMSTRONG.]

In last Tuesday's meeting, when the time came for general discussion of the subject, it really was so late I did not care to criticise some of the points brought up. However, there is just one point in the papers that were read which ought not to stand without criticism; I mean the sacrifice of regulation for efficiency. The writer of each paper seemed to consider that in the

design of an alternator the all important factor was the obtaining of high efficiency. To regulation they paid very little attention. This latter seemed to be considered a very secondary matter.

Suppose we consider a 60,000 volt long distance transmission line; one central station and two substations; one substation being 50 miles distant from the central station and the other 10 miles. Now, if one of these substations, say the 10 mile one, should be cut off suddenly, there would be a certain rise in voltage at the central station. This rise would be magnified greatly at the other end of the 50 mile line, on account of the condenser effect in the line. This increase in voltage would be liable to cause trouble at this second substation that is still running. I therefore think that if designers would sacrifice a few per cent. efficiency in a machine and obtain better regulation, it would reduce a great deal of such trouble as might arise in the above-mentioned case. I therefore think that, in future, more importance ought to be given to regulation in the design of alternators.

[COMMUNICATED AFTER ADJOURNMENT BY MARIUS LATOUR.]

In the paper of Mr. Adams read May 19th, 1903, he appears to recognize several distinct methods for compounding alternators provided with a commutated winding. In fact, these several methods are very similar for the simple reason that a compound excitation can only consist of the combination of a series and of a shunt excitation.

The most natural method of carrying out this combination in practice is to arrange two circuits and two commutators on the rotor. But it is easy to see that the use of a compensating transformer is an equivalent.

For example, when using two circuits and two commutators, assume that the series excitation current is obtained from a series transformer K, as is shown in Fig. 1. where the series circuit is alone represented. It is evident that by suitably setting the brushes $a\ b\ c$ the armature reaction can be annihilated in both direction and form.

If the self induction of each secondary of the series transformer K with three-phase connections is represented by l, the ohmic resistance of one-phase of the excitation circuit by r and the frequency of induced currents by w the brushes should be set in such a place as to give:

$$A\,o\,a = \frac{\pi}{2} \times Ag^{1}\,\frac{l\,w}{r}.$$

In order to obtain the shunt excitation without the addition of a second winding, we can arrange matters in such a manner that the shunt currents pass through the secondaries of the transformer K (see Fig. 2), these circuits being now closed on the stator winding in place of the special connection of Fig. 1. The secondaries of the series transformer K may be closed on the stator before or

after the primaries and in either case the secondaries of this transformer constitute impedances for the shunt currents. The currents therefore lag by an angle $t g^{-1} \frac{l w}{r}$ and the machine behaves as if the brushes $a\ b\ c$ were placed, for shunt excitation, in the position $A\ o\ a = \frac{2}{\pi} + t g^{-1} \frac{h r}{r} - t g^{-1} \frac{h r}{r} = \frac{2}{\pi}$ and as if the machine were run light all the time. The flux of the armature is annihilated both in direction and form at any load. The machine operates practically at synchronism.

Mr. Adams is certainly in error in saying: (1) That it is impossible to compound rigorously for all loads by means of a com-

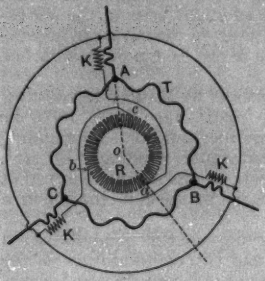

Fig. 1

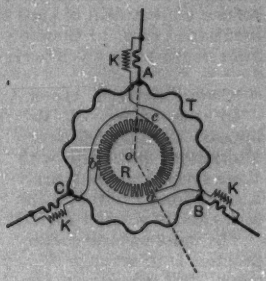

Fig. 2

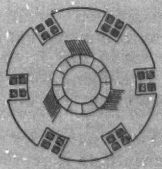

Fig. 3

pensating transformer and, (2) That the machine could not induce currents at constant frequency.

To obtain these two desiderata it suffices properly to design the transformer κ, which, in any case, is of small dimensions. The compensating transformer is my way of compounding the shunt machine.

Concerning my shunt machine working as a motor, it is of interest to read the article of Mr. Bragstad, see *E.T.Z.*, May 21st, 1903.

The commutation of alternators of my design, in which I make use of the ordinary winding of the continuous current armatures

is as good with few bars on the commutator as with many. With a drum winding consisting of twelve coils divided into six slots per complete magnetic circuit (see Fig. 3), the commutation is perfect. The damping of harmonics is produced automatically not only by the short-circuiting of the rotor through the exciting circuit, as before indicated by myself (see *Electrical World*, 1902 page 60), but also by the short-circuiting of the rotor coils through the brushes.

These two ways of damping of harmonics which I have personally discovered are more than sufficient to suppress every harmonic and to give a perfect commutation.

Instead of placing the coils in one slot only it is possible to put them in several slots per hole, as proposed by Mr. Fischer-Hinnen for continuous current dynamos.

BRANCH DISCUSSIONS.

Discussion at Minneapolis, May 1, 1903.

The Minnesota Branch of the Institute held their 12th regular meeting in the Electrical Building at the State University, May 1st. Attendance 22.

The papers on Central Stations by Messrs. Lardner, Junkersfeld and Torchio were read and discussed.

It was stated in Mr. Junkersfeld's paper that the feeders and mains, cables, conduit and Edison tubes require 40 to 48 per cent. of the total investment. Suggestions were made that this investment would be greatly reduced by the use of a higher local distributing voltage, 220–440 volts. The alternating current system throughout, doing away with the rotary converter and substations, was commended because of the smaller investment, lower cost of operation and the decidedly better regulation. Unfortunately, our larger cities now use direct current for local distribution and use direct current arc lamps and motors. In smaller cities, where an alternating current local distribution is used, the decreased cost of distribution and operation, and the better regulation are well known.

A reasonable amount of sectionalizing is considered advisable. Plants and large generating units are now designed to be operated separately whenever it is so desired. But normally, multiple operation of all units and of separated power plants is always advantageous. The total shutdown of a system would not occur when the time limit overload devices are perfectly proportioned.

Referring to Mr. Lardner's paper, the fact that the steam turbine has a relatively high efficiency at light loads commends it to us especially for heavy electric railway work. Here the load factor is very low and the power required fluctuates between wide limits.

The advantages of two large stations of say 5,000 k.w. capacity each, compared with a single station of twice that capacity is recognized for long-distance heavy electric railways as well as for other services. The saving on real estate and installation with one station would be small. The difference in economy of fuel and labor, per k.w. hour delivered to the electric motors, would be very small. The two stations being connected by high voltage transmission lines would operate in multiple and the disabling of part or the whole of one station would leave the railway with a relatively larger available power.

A heavy freight and passenger electric railway, 150 to 500 miles long, should not depend upon one electric power plant. Two or more are preferable. The steam locomotive has fewer links between the coal and the application of power to the wheels and is an example of the present ideas of steam railway companies regarding "The *economical* and *safe* limits in the size of stations."

The electric power plant has a great many links to decrease the reliability of service, which is paramount. The use of two 5,000 k.w. plants, separated 100 miles, would in general give a more safe and reliable design than one 10,000 k.w. plant. We must look at this problem from the standpoint of reliability of service, rather than from the standpoint of economy.

By increasing the number of stations the greater refinement in the one station, brought out in Mr. Torchio's paper, will seldom be required.

A paper read at the 2d extra Meeting of the Schenectady Branch of the American Institute of Electrical Engineers, Union University, Schenectady, New York, May 18, 1903.

A DISCUSSION OF SOME POINTS IN ALTERNATING CURRENT THEORY.

BY W. S. FRANKLIN.

I was bold enough to write several weeks ago to the secretary of the Schenectady Branch of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, suggesting that arrangements be made whereby I might discuss with Mr. Steinmetz some points in alternating current theory with the hope of bringing about among writers on this subject an agreement in regard to certain points in method and notation which would, I think, greatly facilitate educational work in this field.

I was pleased to hear promptly from Mr. Williams that my suggestion had met with the hearty approval of Mr. Steinmetz and that the debate, as Mr. Williams called it, would be set for Monday, May 18. I wish to thank Mr. Steinmetz for his readiness to enter into a discussion with me and I wish to express my high opinion of his ability as a physicist by referring briefly to a short conversation I had with him several weeks ago, a conversation which turned to the discussion of the vacuum tube discharge and of the general question of the relation between temperature and luminous radiation. It pleased me greatly to hear Mr. Steinmetz say that it is a mistake to apply the notion of temperature to the peculiarly disturbed gas in a vacuum tube. I was reminded of the incredulity with which a fellow physicist received a statement from me some six or seven years ago, when we were discussing the question of the temperature of the electric arc—I stated that the arc has no temperature, though it cannot be denied that it is in a certain sense very hot. Mr. Steinmetz's remark also reminded me of a criticism I made several years ago of Duhem's large treatise on Thermodynamics. I took occasion

in reviewing this book to point out a mistaken mathematical development based by Duhem on the false application of the precise notion of temperature to a body or system not in thermal equilibrium. Duhem contended, largely on the basis of this error, that his notion of thermodynamic potential is more definitely usable in thermodynamic theory than the notion of entropy.

Before proceeding to the details of the evening's discussion I wish to state that my discussion will be very largely a discussion of ideas and conceptions with little reference to detailed mathematical developments. I know of only one way to carry on such a discussion and that is to reduce each point in the discussion to its simplest terms and state the result as a fact. One of the General Electric employees said to me some time ago that the trouble with Mr. Steinmetz was that he threw out his statements expecting them to be accepted as self-evident statements of fact. Truly, I cannot see how else Mr. Steinmetz could do. For my part I shall of course endeavor to make my statements as clear as possible, nevertheless I think that the auditors are in for a very considerable share of the effort of the evening's discussion.

My primary object in opening this discussion is to state my position clearly on the following points:

(a) Steinmetz's polar-coördinate method versus the clock-diagram method of representing harmonic alternating electromotive forces and currents.

(b) The necessity of choosing signs, especially in polyphase networks, in order that the physical facts of a problem may be fully and unequivocally represented in the vector diagrams or in the complex equations which form the basis of the solution of the problem.

(c) That Mr. Steinmetz's topographical method does not differ in any essential respect from the vector method of representation, and that Mr. Steinmetz is not justified in his claim that the topographical method is better suited than the vector method to the discussion of polyphase problems where the consideration of algebraic signs is more exacting than in single-phase problems.

(d) In regard to the physical basis of the general equations of the transformer and of the induction motor.

(e) In regard to Mr. Steinmetz's treatment of power and double-frequency products.

POLAR-COÖRDINATE VS. CLOCK-DIAGRAM METHOD.

I think it is of the utmost practical importance, especially to men engaged in educational work, that the relative advantages and disadvantages of these two methods be carefully considered and that the one or the other together with the corresponding convention as to sign of reactance in the complex expression for impedance be finally and universally adopted.

I take it to be self-evident that a pulsating quantity such as an alternating electromotive force or current can be represented only by a thing which pulsates. We should guard ourselves carefully against falling into the notion that a vector represents an alternating electromotive force or current. At least at the outset when we are developing our method, be it Steinmetz's polar-coördinate method or the clock-diagram method, we should have a clear appreciation of all the machinery involved, afterwards it is of course allowable to say, for the sake of brevity, that a certain vector *represents* a given alternating electromotive force or current without describing how the representation is actually accomplished.

In case of the clock-diagram to say that a given vector E *represents* a harmonic alternating electromotive force means that it is a rotating line of which the projection on a fixed line represents the varying values of the alternating electromotive force.

In case of Steinmetz's polar-coördinate diagram, to say that a given vector E *represents* a harmonic alternating electromotive force means that the vector stands for a circle of which it is the diameter and that this circle cuts off from a rotating line a varying segment which represents the varying values of the alternating electromotive force.

The fundamental machinery of representation being thus devised the next step in the development of either method is to establish the addition theorem, namely, that the sum of two harmonic alternating electromotive forces e' and e'' (instantaneous values) is *represented* by the vector sum of the two lines which *represent* the respective electromotive forces e' and e''.

The establishment of this theorem is an extremely simple matter in the clock-diagram method and although it is not a serious matter in the polar-coördinate method it must be admitted that any junior student is likely to be overwhelmed by the unfamiliar mechanism involved. Stated fully, the theorem is as follows in the polar-coördinate method and clock-diagram method respectively:

(a) Two harmonic electromotive forces e' and e'' are represented by the varying segments cut off from one and the same rotating line by two fixed circles of which the diameters are the lines E' and E''. Then the sum $e'+e''$ is represented by the varying segment cut off from the same rotating line by a fixed circle of which the diameter is the vector sum of the two lines E' and E''.

(b) Two harmonic electromotive forces e' and e'' are represented by the varying projections of two lines E' and E'', which rotate at the same speed. Then the sum $e'+e''$ is represented by the varying projection of the vector sum of E' and E''.

I am convinced that neither the clock-diagram method nor the polar-coördinate method has any essential advantage over the other except, perhaps, that the clock-diagram method is more simply related to the fundamental geometrical interpretation of the complex expotential $E\,\varepsilon^{j\omega t}$ as a uniformly rotating vector of length E.

I am convinced that the machinery of the clock-diagram method is much more familiar to every one and simpler than the machinery of the polar-coördinate method.

I consider that the difference in the complex expression of an impedance, namely, $r+jx$ and $r-jx$, which grows out of the differences in the machinery of the polar-coördinate and of the clock-diagram methods is a very serious source of confusion and vexation. I think that we ought all to adopt the clock-diagram method, and the expression $r+jx$ for the impedance of an inductive circuit. I think that all questions of notation are essentially educational questions and I therefore feel justified in taking a stand in this matter in apparent opposition to Mr. Steinmetz; I say apparent opposition because I cannot imagine that Mr. Steinmetz cares anything about the matter except to the extent that he is concerned with the business of education and to that extent he must, I think, agree with me.

Before leaving this discussion of the polar-coördinate method and the clock-diagram method, I wish to call attention to a matter which, in both methods, is more or less perplexing; namely, the question as to the propriety of representing impedance as a vector. In the clock-diagram, electromotive force and current vectors are understood to rotate, while an impedance vector, if one chooses to represent impedance by a vector, is stationary. It is therefore not proper to represent impedance

by a vector in one and the same diagram with electromotive force and current. In the polar-coordinate diagram it is perhaps allowable to represent both impedance and electromotive force or current, it being kept in mind that an electromotive force or current vector stands for a circle and the accompanying machinery for representing a harmonically varying quantity while the impedance vector does not.

NECESSITY OF CHOOSING SIGNS IN COMPLICATED NETWORKS.

Everyone appreciates the importance in general of representing the data of a problem completely and without ambiguity in the geometrical construction in the algebraic formula which is to be used in solving the problem. The choice of signs in a complex network is a matter which touches this general question and I wish to speak especially of the choice of signs in polyphase networks inasmuch as I do not, so far as I see, agree with Mr. Steinmetz in this matter.

In considering a single-phase alternator the electromotive force (or current) can be represented by a given line or by a line in the reverse direction according as we choose to consider the electromotive force as positive or negative when it acts in a given direction. This ambiguity, however, seldom or never leads to confusion in the study of single-phase circuits inasmuch as we quite unconsciously choose the positive direction of electromotive force to coincide with the positive direction of current, and in the study of a single-phase circuit we are concerned only with the relations between the one electromotive force and the one current. When we come, however, to consider a polyphase system we are immediately confronted with the relationship of electromotive forces (or currents) in different circuits and an explicit decision as to signs is absolutely necessary. I gave to-day, before the students of Union College, an elementary discussion of a number of simple problems illustrating this point; namely, (a) the electromotive force and current relations in a two-phase three-wire system. (b) The electromotive force and current relations in Y and Δ connected three-phase alternators. (c) The use of two wattmeters on a three-phase receiving system. (d) The use of two transformers for 3-phase = 3-phase step-down transformation, and (e), the 2-phase-3-phase transformer. I give the most important features of this discussion in an appendix to this printed discussion so as to furnish several examples illustrating the necessity of the choice of signs.

I think that Mr. Steinmetz is wrong in claiming any advantage of his so-called topographical method over the vector method in the clearing up of difficulties arising from the confusion of signs, and I think that the distinction between action and reaction, between impressed electromotive force and counter-electromotive force, although it complicates the difficulties arising from confusion of signs, is a very different matter from that which I have in mind in the above discussion.

The topographical method really contains not the least element of essential difference from the vector method of representation. The two methods differ chiefly in their appeal to the eye and I think that Mr. Steinmetz has been led to attribute greater power to the topographical method for the following reason:

In ordinary alternating current problems we are in nearly all cases concerned with the *addition* of given partial electromotive forces or currents, while in many polyphase problems we are frequently concerned with the *subtraction* of given electromotive forces or currents. Now we are all of us accustomed to picture mentally the sum of two vectors as the diagonal of the parallelogram constructed on the two vectors as sides, but we are not so accustomed to picture the difference of two vectors as the distance between their termini. On the other hand, if only the *terminal points* of two vectors are indicated in a drawing the distance between the points is the simplest notion that can be associated with them. That is, the topographical method accentuates the notion of a difference and in fact this accentuation is not accomplished by making the notion itself more evident in the diagram but by making the notion of a sum less prominent.

I am convinced that the topographical method of Mr. Steinmetz is essentially identical to the vector method, except in the way it appeals to the eye. I think that in its appeal to the eye the topographical method is very decidedly less intelligible than the vector method and I do not think even that the topographical method permits more readily than the vector method of the use of a reference point or region of zero potential. I wish to take this occasion to say that I wholly disapprove of those so-called vector diagrams so frequently used by writers on alternating currents, not however including Mr. Steinmetz, in which the various electromotive forces or currents are represented by sides of triangles without arrow heads. All electromotive force or current vectors should be drawn from one and the same origin and each should have an arrow head. Uncertainty as to which

end of a vector should show the arrow head simply means that the person who is constructing the diagram does not know enough about the concrete facts of his problem to represent them completely and unequivocally in a vector diagram.

The Fundamental Equations of the Transformer and of the Induction Motor.

There is nothing in the teaching of physics so important as to develop in the student the ability to express physical conditions in mathematical form, geometrical or algebraic as the case may be; to reproduce or represent the conditions of a problem adequately as a geometrical construction or as an algebraic formula. Nothing, I say, is so important as this. It is the very essence of effective knowledge in physics, and every bit of attempted instruction which does not contribute directly or indirectly to facility in this representation of physical fact, in terms of our mental tools, is, in my opinion, futile. I think that no one but a teacher of physics can fully appreciate the truth of these assertions and it is far from my intention to criticise Mr. Steinmetz's writings for their meagreness in this respect. Mr. Steinmetz has a right to expect of his readers some degree of facility of the kind here under consideration, and I for one am always glad when I take up a theoretical paper which does not impose a great array of elementary detail upon my attention. I can stand unlimited preliminary statement of fact even when the style is slightly obscure, but reiterate explanation I cannot endure. If anything in this statement be taken by my hearers as a suggestive criticism of Mr. Steinmetz's papers I hasten to assure you of your mistake, although I must admit that Mr. Steinmetz's style has sometimes seemed to me to be slightly obscure. But let us come to the point. Mr. Steinmetz in his discussion of the general equations of the transformer is led by these equations to a series of propositions as to the equivalence of a transformer with its secondary receiving circuit to various series and parallel combinations of simple circuits. Every one of these propositions in my opinion is easily established by the consideration of very simple physical principles, and I think that the general equations of the transformer are properly based upon these propositions which Mr. Steinmetz seems to think are arrived at by means of the general equations.

If these propositions are really dependent upon the general equations of the transformer I certainly do not know where these

general equations come from, nor on what basis of physical fact they stand.

The theory of the transformer may be developed first on the assumption that coil resistances, magnetic leakage and magnetizing current are entirely negligible. This ideal theory, if we may call it such, is of course very simple. The fact is that this ideal theory is the first term in a series of approximations. A second approximation may be arrived at by considering the effects (a) of coil resistances, (b) of magnetic leakage and (c) of eddy current and hysteresis losses and core reluctance, each by itself, the mutual effects of these three items being ignored. This second approximation is accurate enough to meet every demand hitherto made by the practical engineer. The third approximation, which would have to be based on the consideration of the influence of (a) on (b), of (b) on (a), of (b) on (c), of (c) on (b), of (a) on (c) and of (c) on (a), had never been fully worked out so far as I know.

By considering the effects of items (a), (b) and (c) separately, the propositions enunciated by Mr. Steinmetz are easily established and from these propositions the general equations of the transformer can be written down at once.

The general equations may be, and usually are, modified so as to take account *partially* of the influence of items (a) and (b) upon item (c) by using primary induced electromotive force instead of primary impressed electromotive force in the equation for magnetizing current.

The establishment of the fundamental equations of the induction motor, single-phase, and polyphase, and of the repulsion motor, is, in my opinion, accomplished in much the same manner as the establishment of the fundamental equations of the transformer; that is, by first establishing certain simple circuit equivalences by considering separately the effects of magnetic leakage, coil resistances, core losses, etc.

Power and Double Frequency Products.

The product of instantaneous values of an alternating current and electromotive force gives instantaneous power. This instantaneous power reduces to the form

$$p = a + b \sin (2\omega t + \theta)$$

That is, the instantaneous power consists of a constant part $a\,(= E I \cos \theta)$ and a harmonic part which has a frequency

twice as great as that of the given electromotive force and current.

The question is, can this power p be represented by a vector or by the complex algebraical expression for a vector? I think it cannot. In the ordinary vector representation of an alternating electromotive force three elements are involved, two of which appear explicitly in the vector, namely, numerical value and phase; and one of which, the frequency, is involved in the machinery for which the vector stands. Now p contains four elements, namely, a, b, ωt and θ and it cannot be represented by a vector.

It is possible by means of Hamilton's notion of vector products to see the complete representation of $a+b\sin(\omega t+\theta)$ in the product of the two vectors E and I, which represent electromotive force and current respectively, although a difficulty arises in that the vector which represents $b\sin(\omega t+\theta)$ lies out of the plane containing E and I. A more serious difficulty is, I think, that in Hamilton's system the products of the component unit vectors i, j and k are interpreted in a manner which is inconsistent with the interpretation of the product of the horizontal unit vector i and the vertical unit vector j, upon which ordinary complex algebra is based.

In forming the product of the ordinary complex expressions for an alternating electromotive force and an alternating current *it is necessary to adopt a new kind of complex algebra* in order that any part of the product may represent the power developed. The ordinary complex algebra is not available. I do not think that Mr. Steinmetz's discussion of power and double-frequency quantities furnishes a consistent algebra for representing power and I do not think it is advisable or desirable to develop an algebra to meet the requirements of power representation.

Aside from the fundamental impossibility of representing by a vector a notion involving four elements, I note in particular two things to which I take exception in Mr. Steinmetz's discussion, namely,

(*a*) The fundamental equations of interpretation

$$j^2 = +1$$
$$1 \times j = -j$$
$$j \times 1 = j$$

which, according to Mr. Steinmetz, establish an algebra which meets the requirements of power representation do not, I think, furnish the basis of any consistent system of algebra whatever.

The first of these equations seems to be suggested by the fact that a time interval or angle which represents half a cycle for a given frequency represents a whole cycle for double-frequency. The second and third seem to be suggested by the necessity of bringing into the product of two complex expressions those signs which are required to make one part of the product actually equal to the constant part of the power.

(b) The real component of power in Mr. Steinmetz's discussion is the quantity a in the equation

$$p = a + b \sin (2\omega t + \theta)$$

and the imaginary component is the quantity $b \sin (2\omega t + \theta)$. I do not see what possible meaning can be assigned to a vector of which one component is a constant and the other a harmonic function.

APPENDIX.

Examples Illustrating the Necessity of a Careful Choice of Signs in Problems Dealing with Polyphase Networks.

SINGLE-PHASE SYSTEM.

Fig. 1.

Fig. 1 represents a single-phase alternator with its terminals a and b. Suppose that at a given instant the electromotive force acts from a to b at, say, its maximum value. The rotating vector which represents the electromotive force must, at the given instant, be in the position to give its maximum projection but whether in position to give maximum positive or maximum negative projection depends upon whether we choose to consider an electromotive force from a to b as positive or negative. The same remarks apply to the representation of the current delivered by the alternator. If only we choose positive direction of electromotive force and positive direction of current the *same* the relative positions of the electromotive force vector and current vector will be independent of *which* direction is chosen as the positive direction. Therefore no ambiguity can exist provided the same direction is chosen as positive direction both of current and of electromotive force, and the interpretation of the vector diagram is not liable to confusion. This is, however, not the case when we are concerned with the relations

between electromotive forces and currents existing in the separate windings of a polyphase generator.

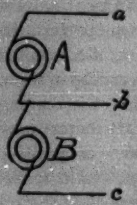

FIG. 2.

TWO-PHASE SYSTEM.

Fig. 2 represents a two-phase alternator with three-wire service mains a, b and c. (The confusion of signs can only occur where the two phases are brought into relation with one and the same element, be it a common main as in this example, a common magnetic element as in the two-phase induction motor, or any other element common to the two-phases.)

Suppose positive signs between mains be chosen from a to b, from b to c and from a to c; and suppose that Fig. 3 is the vector diagram representing the two electromotive forces. Then the electromotive force from a to c is the sum of A and B and it is 45° ahead of B and 45° behind A in phase. If positive signs between mains are chosen from b to a, from b to c and from a to c then with precisely the same actual conditions existing in the system the vector diagram will be as shown in Fig. 4 and the electromotive force from a to c, which is of course exactly the same as before, both in fact and in representation, will be equal to $B - A$, and it will be 45° ahead of B as before and 315° ahead of A in phase.

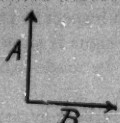

FIG. 3.

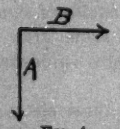

FIG. 4.

Examples of variation of vector diagram with choice of signs along the mains could be easily outlined in the matter of the relations between currents in the mains.

THREE-PHASE SYSTEM.

I shall not take in this case the simplest examples to illustrate the principles under discussion, the examples namely which are furnished by the discussion of current and electromotive force relations in a three-phase three-wire system with Δ-connected and with Y-connected armature windings; but I will take up the discussion of a problem which offers greater intrinsic interest; namely, the problem of the use of two wattmeters for measuring the power delivered to a three-phase receiving system.

THE USE OF TWO WATTMETERS FOR MEASURING THREE-PHASE POWER.

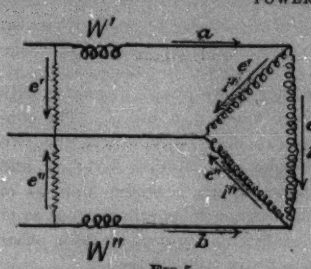

FIG 5.

Fig. 5 shows two watt-meters connected for measuring power delivered to a Δ-connected 3-phase receiving system. In order that the reading of each watt-meter may be considered as positive when the power it measures is *delivered to* the receiving system, the positive signs of electromotive forces e' and e'' and of currents a and b must be properly chosen.

There are four systems of signs which meet these requirements, and each of these systems is non-symmetrical with respect to the three receiving circuits. One of these systems of signs is shown in Fig. 5. The choice of sign of e''' and i''' may be made arbitrarily.

Now, a symmetrical choice of signs in a three-phase system gives a symmetrical vector diagram and a non-symmetrical choice of signs gives a non-symmetrical vector diagram. To fix the vector diagram for a given non-symmetrical choice of signs it is best first to choose a symmetrical system of signs, draw a symmetrical vector diagram, and then change signs as desired and reverse the corresponding vectors.

Fig. 6 shows the vectors which represent the three electromotive forces e', e'', and e''' and the three currents i' i'' and i''' in conformity with the choice of signs in Fig. 5.

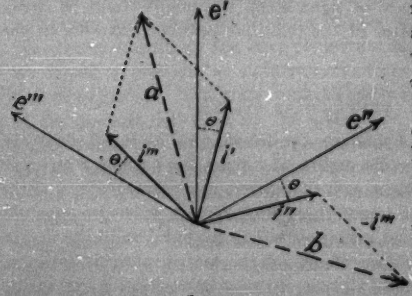

FIG. 6.

By inspecting Fig. 5 it is evident that

$$a = i' + i'''$$
$$b = i'' - i'''$$

from which the vectors representing the currents a and b may be drawn as shown in Fig. 6.

Now, wattmeter W' indicates the average value of the product of e' and a, which is equal to $E' A \cos(30° - \theta)$; and wattmeter W'' indicates the average value of the product or e'' and b which is equal to $E'' B \cos(30° + \theta)$; where E', E'', A and B are the effective values of e', e'', a and b respectively. If the receiving system is balanced $E' = E''$ and $A = B$ so that the two wattmeter readings may be written:

$$W' = k \cos(30° - \theta)$$
$$W'' = k \cos(30° + \theta)$$

When $\theta = 60°$ we have the well-known condition in which $W'' = 0$ and the wattmeter W' measures all the power. When $\theta > 60°$ W'' is negative and is to be subtracted from W' to give the power delivered to the receiving system.

A paper read at a meeting of the Chicago Branch of the American Institute of Electrical Engineers, May 19, 1903.

SOME FEATURES OF TELEPHONE TRAFFIC AND THEIR EFFECT ON SERVICE.

BY J. G. WRAY.

Traffic, in the strict acceptance of the term, implies the transfer of goods or commodities from one person to another in exchange for other goods or commodities or for money. We, of course, may consider as traffic exchange of ideas over a telephone wire from one person to another and such a construction puts telephone calls within the meaning of the word.

Mr. S. J. Larned in a recent paper before the Chicago Electrical Club enumerated several essentials of good telephone service:—

A vast clientele. It should be possible to reach all of one's friends or business correspondents by telephone. Uniform answering. There should be no long wait for the response of an operator. Rapid and accurate service. The party called for should be obtained quickly and there should be no interruption of the conversation. Communication should not be prevented by busy lines. (Busy calls arise from the fact that two persons desire to talk to a third party at the same time and such instances are common on very busy telephone lines.) Apparatus and other plant should be well maintained. The telephone and its wires should receive proper expert attention with a view of minimizing interference with the service, and when out of order should be repaired promptly. Courteous treatment of the subscriber by the telephone employees and *vice versa*.

Consider first the part the subscriber plays in telephone traffic and in making either for good or for bad service. I am perhaps open to criticism from the laymen when I say that the subscriber's part is an important one and often militates against good service. Who has not called for a number and after waiting for a few min-

utes hung up the receiver with imprecations against the telephone service? In the meantime the telephone apparatus has perhaps performed its functions properly and the operator is in a fair way to get the called subscriber. When the latter answers—he may not have answered promptly—and finds no one on the line, he, and not the calling subscriber is certainly the aggrieved party.

False calls are a frequent and annoying source of complaint against the service and are caused in many ways in addition to the one just named. The calling party may give the wrong number or the wrong office. The number or office may be misunderstood by the operator, or the calling subscriber may change his mind and decide not to make the call. In case the call is from a subscriber in one office to a subscriber in another office there is of course always a chance of a misunderstood number resulting in a call for the wrong party.

I recently noticed a curious fact in observing traffic from 10-party-line subscribers in a city not 1,000 miles from Chicago. I noted the extreme smoothness and accuracy of the service, the apparent absence of any hitches or complaints and was surprised when I learned that the operator's load was practically 30 per cent. higher than operators' loads in similar service in Chicago. I can explain this condition only by assuming that the operator had the intelligent and courteous coöperation of the subscribers and this was apparent from such observations as I was able to make during a two hours' visit in the office.

Calls should be answered promptly lest they become lost and the called subscriber lose perhaps a chance for an important business transaction. Prompt answering and short conversations will always tend to keep the line free for other inward calls and will minimize busy calls, which more than anything else are a source of bitter complaint.

Practically 20 per cent. of all calls made are never completed because the line called for is busy. About four calls out of every five are completed properly. This feature of telephone traffic is one of the most annoying to the subscriber, but unfortunately is almost beyond the control of the telephone company. Many busy calls result, of course, from the fact that certain lines are in use a great deal of the time. The subscriber may come to a realization of the fact that as the business on his line increases the probability that he is excluding other business calls with a busy signal increases even more rapidly. However, inasmuch

as there is always the possibility that two subscribers may desire to talk with a third subscriber at the same time there will always be calls stopped by the busy signal.

Other things being equal, the busy reports that may be expected from telephone lines will become more numerous and will increase with the number of conversations carried on over that line. In actual practice, however, other factors enter in. The New York City telephones, for example, are reported busy about as often as the Chicago telephones, practically 20 per cent. The number of conversations per line on New York telephone lines, however, is much less than on the Chicago lines. We would therefore ordinarily expect fewer busy reports from the New York lines. The other factors entering in this particular case are undoubtedly shorter conversations by Chicago telephone users and a disposition to rent additional telephone wires where circumstances seem to warrant it. Another factor which has even greater bearing is the fact that the New York City telephone calls are crowded into a shorter day and that hour for hour the lines are nearly as busy as in Chicago.

Leaving aside any further discussion of the part the subscriber may have in that which will militate for good service we have only to remark that if the subscriber would exercise the same courtesy and good judgment in his use of the telephone that he would show under ordinary circumstances in dealing with his business acquaintances face to face there would be a marked improvement in the service and the trials of the unjustly maligned telephone operator would be considerably mitigated.

Uniform answering with rapid and accurate service can only be accomplished by minimizing the work on each call and by giving an operator enough calls to keep her busy and not any more than she can handle properly. The service may be considered as being good when the average answering is in 6 or 7 seconds and when say 95 per cent. of all calls are answered within 10 seconds. This grade of service is obtained only under favorable conditions. The operator must not be overworked and she must be continuously under a competent supervising operator. The practice is to have a supervisor for every eight or ten operators. This supervisor should work under the direction of a chief operator.

One of the requisites of good service mentioned above is that the time and operations required of an operator on each individual call shall be a minimum. Obviously, the

operator has no time for discussions with the subscribers on the merits of a complaint. These are turned over to the supervising operator for adjustment. It is the aim of the operating manager so to control the two factors just named that good service will result. By the proper manipulation of the intermediate distributing board he may, by increasing or decreasing the number of lines that an operator must answer, keep the operators load uniform under the fluctuations of traffic experienced in a telephone exchange. He must also minimize the work and time required of an operator on each particular call. This is done by paring down phrases that the operator must use, by providing machinery to eliminate certain manual operations, and easily read and interpreted signals to keep her informed as to the condition of the line called for, whether busy or out of order, or of the various phases of the connection; and charts to indicate changes of number of service, etc.

In a typical telephone exchange the load curve indicating the volume of traffic shows during the midnight hours a value of from 1/10 of 1 per cent. to perhaps 5 per cent. of the maximum hourly load. This period of light load will vary from 7 to 14 hours, depending upon the location of the exchange and the habits of the telephone users. In the offices of the business district of a city, like Chicago, very few calls are made between 7 P. M. and 7 A. M. Between the hours of 10 P. M. and 7 A. M. the calls per hour will vary from 1/10 of 1 per cent. to perhaps 1 per cent. of the maximum. Between the hours of 7 and 8 in the morning traffic will rise to perhaps 5 per cent. of the maximum. The rise will be extremely rapid, until the maximum load of the exchange is reached between 10 and 11 in the morning. About the noon hour there is a cessation of business and the telephone traffic curve shows a drop of perhaps 40 per cent. below the maximum. After the lunch hour when business has been resumed the traffic curve rises to an afternoon maximum between 2 and 3 o'clock. This maximum will be less than the maximum in the morning and will in a typical office approximate 80 per cent. of the maximum traffic of the day. From 3 P.M. until 5 or 5.30 P.M. there will be a rapid decrease in the traffic load with an almost complete cessation of business at 6 P.M.

In a residence district the slump of traffic at noon-time is not very well marked. There is, however, a decrease in the number of calls made late in the afternoon and a corresponding increase in the number of calls for the telephones of a residence district,

the latter arising from the fact that the head of the house wishes to explain why he cannot come home for dinner, or to announce that he wishes to bring a friend. The evening traffic is also a feature of the residence district. Social calls are made, appointments for the theatre, invitations, etc. Evening traffic of a residence district often continues heavy until 9 or 10 o'clock, indeed, in one of the Chicago offices the evening traffic runs from 30 to 60 per cent. of the maximum and heavy traffic is maintained until nearly midnight. The curve of traffic indicates in a measure the habits of the people in the district.

In the Main office district in Chicago the business day may be said to have begun at 8.30 in the morning. There is a partial cessation of business for luncheon between 12.30 and 1.30 o'clock and the business day closes at about 5.30 P. M. For Central office also in the downtown district the business day is from 8.30 in the morning until 5.30 in the afternoon with scarcely any let up for lunch. Lawyers predominate in the Central district.

In Harrison office the day is the same as for Central and Main, but there is a marked reduction in the traffic between 12.30 and 1.30 o'clock.

The South office business day is practically from 8 o'clock in the morning until 9 o'clock in the evening, and even later, with no indications of a luncheon hour. North office telephone users are satisfied with a shorter day than the people of South office district, the limits being from 8 o'clock in the morning until 8 o'clock in the evening. For West office the limits are from 8.30 in the morning until 9 in the evening.

For Monroe office the traffic shows heavy business from 7.30 in the morning to 6 o'clock in the evening with a distinctly marked lunch hour between 12 and 1. Monroe district is a manufacturing district.

Canal office traffic is largely like Monroe, extending from 8 in the morning until 5.30 P. M., with noon hour between 12 and 1.

Yards office telephone users like those of Monroe office begin in the day early and business is in full swing about 7.30 and continues until 5.30 with noon hour between 12 and 1.

In Wentworth district, out in Englewood, the business of the day is done between 8 A. M. and 6 P. M., with some indication that the people have lunch between 11.30 and 1 o'clock.

Hyde Park and Oakland offices, both in residence districts of similar character, show heavy traffic between 8 A. M. and 8 P. M., with no trace of an hour for luncheon.

Lake View office, also in a residence district, shows the work day beginning at 7.30 A. M. and extending until 8.30 P. M. The habit of early rising was evidently formed before the advent of the Northwestern Elevated.

A similar comparison of traffic load curves of other cities will be of interest. In Philadelphia, for example, we find the heavy traffic between 9 A. M. and 5 P. M., with lunch between 12 and 1.30.

In Boston the traffic shows a work day from 9 A. M. to 5 P. M., with time for luncheon in different offices varying from one and a half to two hours, between 12 and 2 o'clock.

New York telephone users seem to take life even more serenely than those of Philadelphia or Boston and we find the work day beginning as late as 9.30 in the morning and ending at about 4.30 in the afternoon, with two hours for lunch between and 12 and 2 o'clock.

Telephone traffic varies with the seasons as well as with the time of day.

The Canal office district of the Chicago Exchange shows a fluctuation of 50 per cent. between summer and winter traffic. This is caused by the vast lumber interests of the district, which practically close down during the winter months. There is a heavy rush of traffic in April and May, followed by a 40 per cent. reduction in traffic during July and August. In the fall business increases to a maximum in September. This is followed by a 50 per cent. reduction in traffic, culminating in January. A change in the character of the traffic from Canal district, however, has been noticed within recent years and the wide variations of traffic with the seasons are less marked. This is undoubtedly due to the change in the character of the district with the gradual building up of vacant prairie with residences, small shops, saloons, etc.

The traffic of all offices slumps decidedly during the summer months. There is a reduction of perhaps 30 per cent. during July and August, the vacation period.

The volume of traffic of a telephone exchange is also an unfailing index of general business conditions. This is shown by the fact that during 1894, 1895 and 1896 there was a very slight increase in traffic. With the return of prosperity, however, the traffic has increased by leaps and bounds until now it will approximate four times as heavy as during 1895 and 1896.

In passing it will be of interest to note that for 10 hours per day the traffic of Chicago Exchanges ranges above the average hourly

traffic figured on a 24 hour basis. For the other 14 hours per day the traffic is much lower than the average hourly traffic.

The average traffic for the maximum hour is about 2½ times the average traffic of the day, and perhaps 200 or 300 times the traffic of the hour of minimum traffic. The percentages and ratios of traffic given herein take no account of rushes of traffic for short intervals due possibly to the news of a prize fight, a fire, a panic or a foot ball game. These and the tremendous rushes of traffic always preceding or following every important holiday make a severe test of the resources of the operating plant.

The traffic of Saturday forenoon is always the heaviest of the week and is taken as a basis for the adjustment of operator's loads and the loads on trunk lines. The adjustment of the operator's load must be made with a view of handling the traffic well during the busiest hour of the day. Experience has shown that approximately one-eighth of the business of the entire 24 hours must be handled during the busiest hour.

From the above it can be readily seen that the capacity of the operators and the physical telephone plant must be extremely flexible to take care efficiently of the rapid and extremely wide fluctuation in loads just described.

To the advantage of the telephone manager be it said that the human machine is extremely well adapted to the handling of this fluctuating load. A well-trained operator will frequently take three or four calls in rapid succession and complete them almost simultaneously.

Just a word on the efficiency of the telephone plant. Assuming an efficiency of 100 per cent., when all the subscribers' lines are in use all the time, we find that in actual practice they are working under an efficiency of only 2 or 3 per cent.

Assuming 100 per cent. efficiency when the apparatus used by an operator is in use all the time we find that in actual practice it is working under an efficiency of 25 per cent.

Thousands of dollars worth of multiple jacks lie in the switchboard practically idle. Some are perhaps never uesd.

The traffic of a telephone exchange determines the capacity and design of a telephone central station equipment and the size of its operating force. Changes in traffic whether a decrease due to business depression, a change of contracts to a message rate basis or to any other cause; or an increase caused by new telephone subscribers, by better business conditions or perhaps by a change of policy in the matter of party lines or Private Branch

Exchanges must be met promptly by a corresponding readjustment of facilities and operating force to enable the business to be carried on economically and well.

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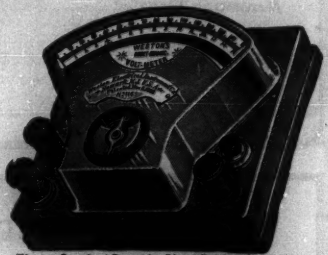

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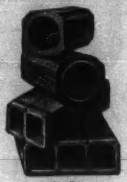

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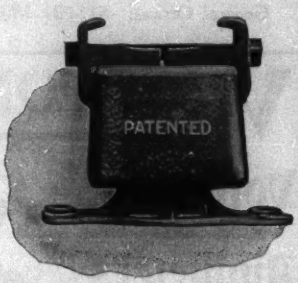

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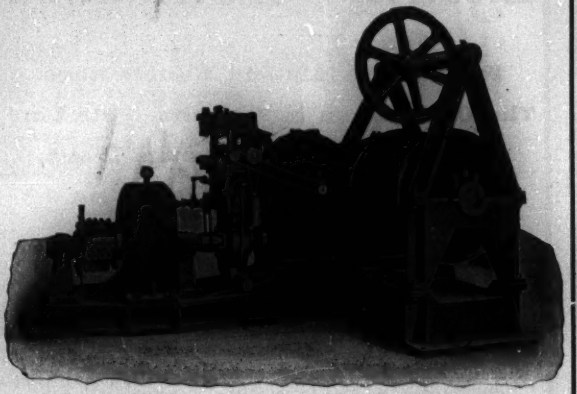

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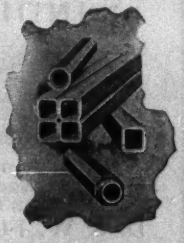

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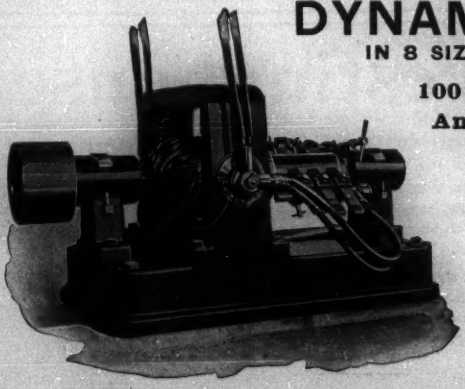

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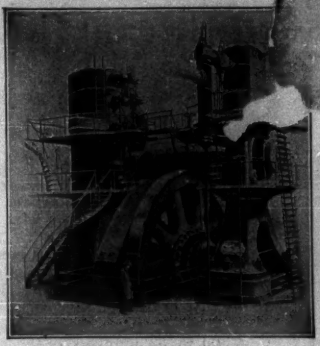

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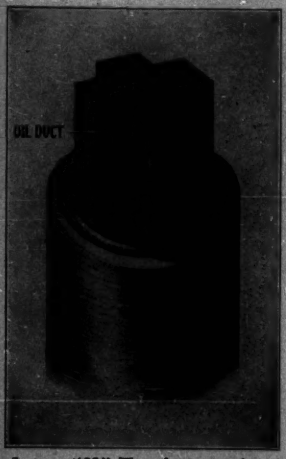

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